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**PERFORMANCE EVALUATION OF THE
TCE CATALYTIC OXIDATION UNIT AT
WURTSMITH AFB**

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FINAL REPORT

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13. ABSTRACT (Maximum 200 words) A catalytic oxidation unit, also commonly known as a catalytic incinerator, is an emission control device to treat air streams contaminated with volatile organic compounds (VOCs). At Wurtsmith AFB (Oscoda MI), a catalytic oxidation unit treats the effluent air from an air stripping operation which transfers VOCs, chiefly trichloroethylene (TCE), from groundwater to air. Air stripping has been proven to be effective and economical for removing VOCs from groundwater; however, some states require that an emission control device be used in conjunction with the air stripping unit since air stripping merely transfers the VOCs from the water phase to the air phase. Incineration is an attractive choice for emission control since the contaminants are destroyed on site. A catalytic oxidation unit is preferred to a thermal incinerator because the unit operates at a lower temperature to obtain high destruction efficiencies so less fuel is required to operate the catalytic oxidation unit. The purpose of this project was to evaluate the catalytic oxidation unit at Wurtsmith AFB. (Continued on reverse)					
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13. Abstract (continued).

The results obtained from this study indicated that the catalytic oxidation unit at Wurtsmith AFB destroys TCE with 99 percent efficiency when it is operated at the vendor recommended catalyst bed temperature of 370 °C (700 °F) and when the unit contains ≥19 cm (7.5 inches) depth of catalyst as indicated by the pressure drop across the catalyst bed. Benzene and toluene were the products of incomplete combustion observed most often and in the highest concentrations (up to 0.35 ug/L and 0.87 ug/L, respectively). The results indicated that the formation of these compounds was not due to the oxidation of the TCE, but the actual mechanism responsible for their formation was not identified. The utilities cost for operating the air stripping columns and the catalytic oxidation unit in fiscal year 1991 averaged \$0.36 per 1,000 gallons of water treated.

EXECUTIVE SUMMARY

A. OBJECTIVE

Building 5000 at Wurtsmith Air Force Base (AFB) is the site of an effort to remove volatile organic compounds (VOCs), chiefly trichloroethylene (TCE), from groundwater by air stripping with emissions control. A catalytic oxidation unit is used as the emissions control device. The Air Force Engineering and Services Center at Tyndall AFB contracted the Oak Ridge National Laboratory to analyze and evaluate the full-scale catalytic oxidation unit. The evaluation included obtaining data on the destruction efficiency of the preheater and the catalytic reactor. The evaluation also included determining if there were any products of incomplete combustion (PICs) in the effluent of the preheater or the catalytic reactor. The final element in the evaluation was the collection of accurate utility costs for operation of the catalytic system.

B. BACKGROUND

Air stripping has been proven to be effective and economical for removing VOCs from groundwater; however, some states require an emissions control device to be used in conjunction with the air stripping unit since air stripping merely transfers the VOCs from the water phase to the air phase. The states that require emissions control have placed limits on the quantity of organic contaminants released to the atmosphere. Incineration is an attractive choice for emissions control since the contaminants are destroyed on site. A catalytic oxidation unit is preferred to a thermal incinerator because the unit operates at a lower temperature to obtain high destruction efficiencies so less fuel is required to operate the catalytic oxidation unit.

C. SCOPE

Four series of samples were collected from the catalytic oxidation unit. The samples were collected in October 1989, February 1990, August 1990, and May 1991. Samples were collected simultaneously from the feed, preheater effluent, and stack effluent while operating the unit at catalyst bed temperatures ranging from 315 to 480°C (600 to 900°F).

D. METHODOLOGY

The collection of samples for volatile organic compounds was the major emphasis of this project. A volatile organic sampling train (VOST) was used for the collecting these samples. The VOST is the EPA's Method 30 for the collection of volatile principal organic hazardous constituents from the stack gas effluents of hazardous waste incinerators.

E. TEST DESCRIPTION

The sampling procedure allowed the catalytic oxidation unit to attain steady-state conditions when it was necessary to change the catalyst bed temperature. The unit was allowed to operate one hour after reaching the desired catalyst bed temperature.

The VOST method traps the VOC contaminants on Tenax® resin and activated carbon traps. These traps are removed from the sample train, shipped to the analytical laboratory, thermally desorbed, and analyzed by gas chromatography/mass spectrometry (GC/MS).

Tedlar® bag samples were collected during the August 1990 sampling series. These samples were also shipped to the analytical laboratory and analyzed by GC/MS.

Samples were collected in the October 1989 sampling series to determine the concentration of hydrochloric acid (HCl) and chlorine (Cl₂) in the air stream as it passed through the catalytic oxidation unit. These samples were collected by Research Triangle Institute and analyzed by ion chromatography.

F. RESULTS

The results obtained from this study indicated that the TCE catalytic oxidation unit at Wurtsmith AFB destroys TCE with approximately 99 percent destruction efficiency when it is operated at the vendor-recommended catalyst bed temperature of 370°C (700°F) and when the unit contains greater than or equal to 19 cm (7.5 inches) depth of catalyst as indicated by the pressure drop across the catalyst bed. Benzene and toluene were the PICs observed most often and in the highest concentrations (up to 0.35 µg/L and 0.87 µg/L, respectively). The results indicate that the formation of these compounds was not due to the oxidation of the TCE, but the actual mechanism responsible for their formation was not identified. The utilities cost for operating the air stripping columns and the catalytic oxidation unit in fiscal year 1991 averaged \$0.36 per 1000 gallons of water treated.

G. CONCLUSIONS

The results obtained in this study of the TCE catalytic incinerator are useful to Air Force personnel that are responsible for the operation of this unit.

H. RECOMMENDATIONS

The major contaminant of concern in this study was TCE, and the destruction efficiency results are reported in terms of destruction of TCE. Therefore, these results are not necessarily applicable to oxidation units used for the destruction of other volatile compounds (e.g., benzene). Therefore, it is recommended that similar units that treat volatile organic compounds other than TCE should also be sampled for comparison to the results of this project.

PREFACE

This report was prepared by the Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge TN 37831-6044, for the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall Air Force Base FL 32403-6001, as partial fulfillment of the statement of work entitled "Air Stripping with Emissions Control" in accordance with DOE Interagency Agreement No. 1489-1489-A1. The period of performance of the work was from October 1989 to October 1991. Oak Ridge National Laboratory is managed by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

This document details the results of activities performed under an amendment to the original statement of work. The AFESC/RDVW Project Officer for this effort was Captain Edward G. Marchand.

The author expresses his appreciation to Don Kelsheimer, Mark Burdette, Neal Wilson, Jim Dunlap, and Luther Gibson of the Stack Sampling Group at the K-25 Site, Oak Ridge TN, for their assistance in sampling the catalytic oxidation unit.

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The author also expresses his appreciation to the Environmental Coordinators Office at Wurtsmith AFB, and his special thanks to Mr. Mike Nicklow and Mr. Mike Zak for their assistance and cooperation.

Mention of trademarks or trade names of material and equipment does not constitute endorsement or recommendation for use by the Air Force, nor can the report be used for advertising the product.

This report has been reviewed by the Public Affairs (PA) office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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LIST OF ABBREVIATIONS

AFB	Air Force Base
ARI	ARI International
CDE	Catalyst Bed Destruction Efficiency
DCE	1,2-dichloroethylene
EPA	Environmental Protection Agency
GC/MS	Gas Chromatography/Mass Spectrometry
ITAS	International Technology Analytical Services
ODE	Overall destruction efficiency (percent)
PDE	Preheater destruction efficiency (percent)
PICs	Products of Incomplete Combustion
RTI	Research Triangle Institute
TCE	Trichloroethylene
VOC	Volatile Organic Compound
VOST	Volatile Organic Sampling Train

LIST OF SYMBOLS

BTU	British Thermal Unit
Cl ⁻	Chloride ion
Cl ₂	Chlorine
°C	Degrees celsius
°F	Degrees fahrenheit
ft ³	Cubic feet
ft ³ /min	Cubic feet per minute
gal/min	Gallons per minute
hr	Hour
HCl	Hydrochloric acid
H ₂ SO ₄	Sulfuric acid
KWH	Kilowatt-hour
L/min	Liters per minute
m	Meters
mL	Milliliters
m ³	Cubic meters
m ³ /s	Cubic meters per second
M _F	Mass of component in feed (μg)
M _P	Mass of component in preheater effluent (μg)
M _S	Mass of component in stack effluent (μg)
N	Normal
NaOH	Sodium hydroxide
ppmv	Parts per million by volume
Greek Symbols	
μg/L	Micrograms per liter
μg/mL	Micrograms per milliliter

FINAL REPORT ON THE PERFORMANCE EVALUATION OF THE TCE CATALYTIC OXIDATION UNIT AT WURTSMITH AFB

SECTION I

INTRODUCTION

A. OBJECTIVE

Building 5000 at Wurtsmith Air Force Base (AFB) is the site of an effort to remove volatile organic compounds (VOCs), chiefly trichloroethylene (TCE), from groundwater by air stripping with emissions control. The Air Force Engineering and Services Center at Tyndall AFB contracted the ORNL to analyze and evaluate the full-scale catalytic oxidation unit. The evaluation included obtaining data on the destruction efficiency of the preheater and the catalytic reactor. The evaluation also included determining if there were any products of incomplete combustion (PICs) in the effluent of the preheater or the catalytic reactor. The final element in the evaluation was the collection of accurate utility costs for operation of the catalytic system.

B. BACKGROUND

Operation of the air stripping with catalytic oxidation system began in October 1987. The contaminated groundwater is pumped to the surface and contacted countercurrently with air in two packed columns in series to transfer the VOCs from the water to the air. A flow diagram of this process is shown in Figure 1. The second packed column functions as a polishing step prior to discharging the water to a sewer drain. The air exiting from the first packed column contains most of the volatile compounds that were in the groundwater, and it is directed to the catalytic oxidation unit to destroy the VOCs, then released to the atmosphere. The air stream from the second packed column is released directly to the atmosphere since it only contains very minute amounts of the contaminants. The air stripping system was designed to treat 833 liters/minute (220 gallons/minute) of water; however, the system is usually operated in the range of 568 to 643 liters/minute (150 to 170 gallons/minute).

The catalytic oxidation unit was fabricated by ARI International (ARI). It destroys the VOCs in the air stream by contacting the air with a fluidized bed of catalyst granules at a controlled temperature. The catalytic oxidation unit includes a natural gas flame preheater to elevate the air stream temperature to the catalyst bed temperature. The oxidation unit is designed to treat 0.57 m³/second (1200 standard ft³/minute), and Wurtsmith personnel normally operate the unit at the ARI recommended catalyst bed temperature of 370°C (700°F).

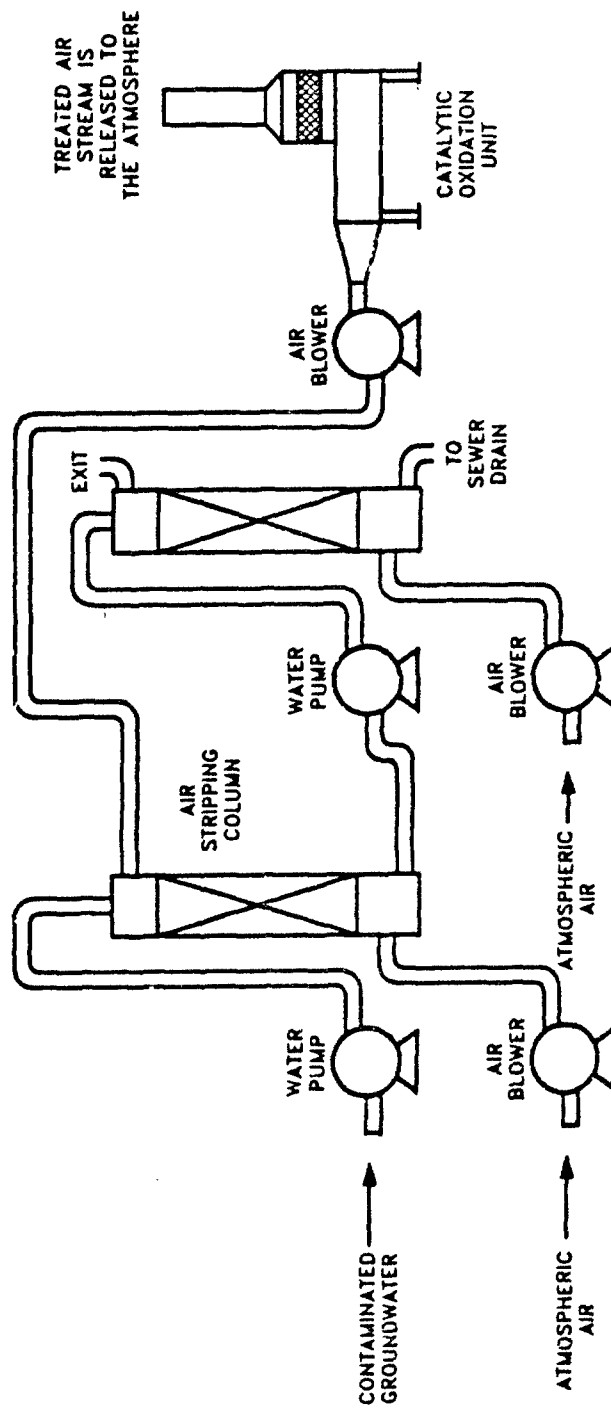


Figure 1. Flow Diagram of Air Stripping With Emissions Control Process.

The catalyst granules in the fluidized-bed oxidation unit are composed of an aluminum oxide support impregnated with chromium.* The catalyst is normally attrited because of the constant grating of the granules against each other, so the catalyst must be periodically replenished. The depth of a full load of catalyst for this unit is approximately 20 cm (8 inches), and the catalyst bed chamber is approximately 0.8 m² (9 ft²) in cross section. The pressure drop across the catalyst bed is directly proportional to the depth of the catalyst bed. According to a manufacturer's representative, 1 inch of water pressure drop corresponds to approximately 1 inch depth of catalyst in the bed.* The pressure drop across the catalyst bed was observed to decrease approximately 124 Pascal (0.5 inch of water) in four months operating time because of the catalyst attrition.

Wurtsmith personnel monitor the air stripper performance by routinely obtaining water samples from (1) the influent to the first column, (2) the effluent from the first column (also the influent to the second column), and (3) the effluent from the second column. Figure 2 is a plot based on the results from these samples. The concentration of TCE stripped from the water by the first column (that is, the difference in TCE concentration of influent and effluent water from column 1) and the corresponding estimated concentration of TCE in the air stream treated by the oxidation unit are shown as a function of the sampling date. The solid line in Figure 2 represents a linear regression of the data. Calculation of the TCE concentration in the air stream assumed an average influent water rate of 585 liters/minute (155 gallons/minute) to the air strippers and 0.53 m³/second (1120 ft³/minute) stripping air. These data are useful for estimating the concentration of TCE in the air stream during the sampling periods performed for this study.

C. SCOPE

Four series of samples were collected from the oxidation unit over approximately 19 months. Table 1 shows the sampling date(s), pressure drop across the catalyst bed, and the corresponding space velocity for the four series of samples. The increasing space velocity is due to the attrition of the catalyst, whereas, the decreased space velocity is due to replenishment of the catalyst.

The stoichiometric equation for the complete oxidation of TCE (C₂HCl₃) is shown in Equation (1) (Reference 1).



*M. Bailey, ARI, telephone conversation, 21 June 1990.

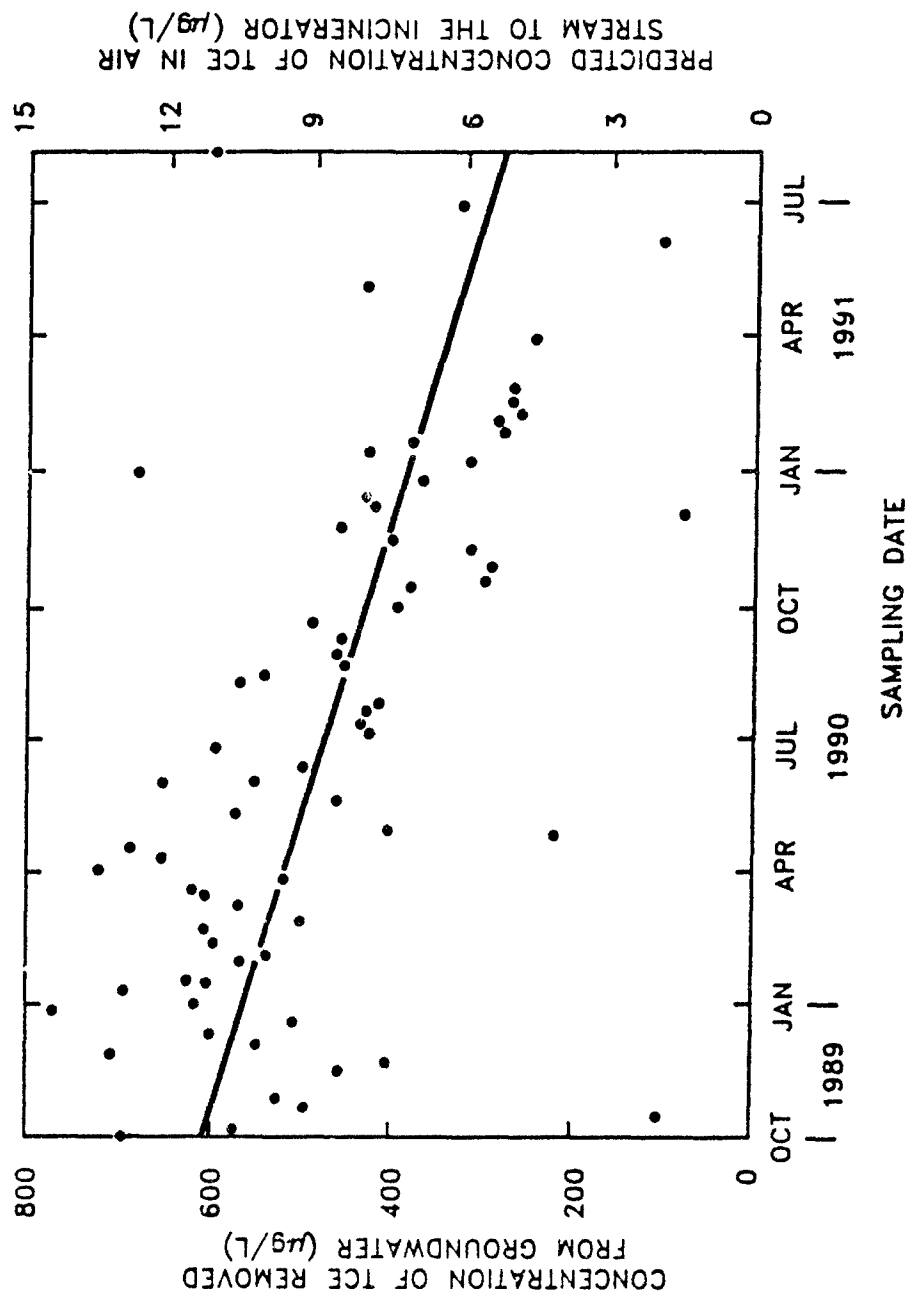


Figure 2. Data from Wurtsmith Water Samples.

TABLE 1. CONDITIONS FOR SAMPLING SERIES

Sampling Series	Sampling Date(s)	Catalyst Bed Pressure Drop (Pascal)	Space Velocity (hr ⁻¹)
1	Oct. 11 - 13, 1989	1,850	12,300
2	Feb. 21, 1990	1,730	13,300
3	Aug. 27 - 28, 1990	1,490	14,600
4	May 7 - 8, 1991	2,080	11,000

This equation shows that the expected products from the oxidation of TCE are carbon dioxide, hydrogen chloride, and chlorine. Since the oxidation is not 100 percent efficient, it is not unexpected to find organic compounds in the stack effluent that were originally present in the feed stream. As previously indicated, the identification of PICs was an objective of this project. For the purposes of this report, a PIC is an organic compound found in the preheater effluent and/or the stack effluent that was not found in the feed stream. The Environmental Protection Agency (EPA) has identified three potential mechanisms responsible for the existence of PICs from the combustion of organic compounds (Reference 2):

1. The compounds were originally present in the incinerator's feed stream but not previously identified through waste stream analysis.
2. The compounds were introduced from sources other than the waste stream, (e.g., combustion air or auxiliary fuel).
3. The compounds were actual combustion byproducts of the primary organic compounds in the incinerator feed stream.

Each of these mechanisms has the potential to contribute to the formation of PICs in this study. With regard to Mechanism 1, the PICs could be contaminants which were co-stripped from the groundwater, but with concentrations overshadowed by the concentration of TCE. Therefore, the compounds were nondetectable at the GC/MS sensitivity level used to quantify the TCE in the feed stream. Mechanism 2 potentially contributed by the introduction of contaminants through the natural gas used to preheat the feed stream. This project did not obtain samples of the natural gas, and the

purity of the natural gas is unknown. It is also plausible that PICs are formed during the combustion of natural gas (Reference 3). Mechanism 3 is potentially viable and cannot be disregarded unless otherwise proven.

A literature review indicated that toluene and benzene are the most common PICs formed from the thermal destruction of hazardous waste. Other commonly occurring VOCs include carbon tetrachloride, chloroform, methylene chloride, tetrachloroethylene, 1,1,1-trichloroethane, and chlorobenzene (Reference 4).

SECTION II

AIR SAMPLING METHODOLOGY

A. SAMPLING PLAN

Sampling ports were installed at three locations of the oxidation unit: (1) inlet (feed), (2) preheater effluent (catalyst bed inlet), and (3) stack effluent (catalytic bed exit). Figure 3 is a schematic of the catalytic oxidation unit and shows the sampling port locations. Simultaneous samples were obtained from each location to account for any potential variation in the feed stream composition with time. Three methods of sampling were performed: (1) volatile organic sampling train (VOST), (2) an impinger train for determining the concentrations of hydrogen chloride (HCl) and chlorine (Cl_2) in the air streams, and (3) Tedlar® bag. Table 2 summarizes the overall sampling plan.

The objectives of the first sampling series were to characterize the oxidation unit's performance with respect to catalyst bed temperature, and to provide the baseline for comparing the performance of the oxidation unit and its catalyst by length of service. VOST samples were acquired at catalyst bed temperatures of 370, 425, and 480°C (700, 800, and 900°F). These temperatures were measured by the oxidation unit's monitoring thermocouples. There were no noticeable differences between the inlet and outlet temperatures of the catalyst bed. In addition to the VOST samples, Research Triangle Institute (RTI), Research Triangle Park, NC, collected samples for determining the concentrations of Cl_2 and HCl at the catalyst bed temperature of 480°C (900°F).

The second series of samples was collected to determine the oxidation unit's performance with respect to operating time. VOST samples were collected only from the feed and stack effluent streams and only at the catalyst bed temperature of 370°C (700°F).

The objective of the third series of samples was to obtain more performance data with regard to catalyst bed temperature. Of particular interest was whether the oxidation unit could achieve a high destruction efficiency at a catalyst bed temperature lower than ARI's recommended temperature. Samples were collected from all three sampling locations at catalyst bed temperatures of 315, 370, and 425°C (600, 700, and 800°F). In addition to the VOST samples, Tedlar® bag samples were collected from the stack effluent while controlling the catalyst bed temperature at 425°C (800°F). The results from the October 1989 sampling series indicated that the destruction process may be forming benzene and toluene as PICs; however, the results from the February 1990 series indicated

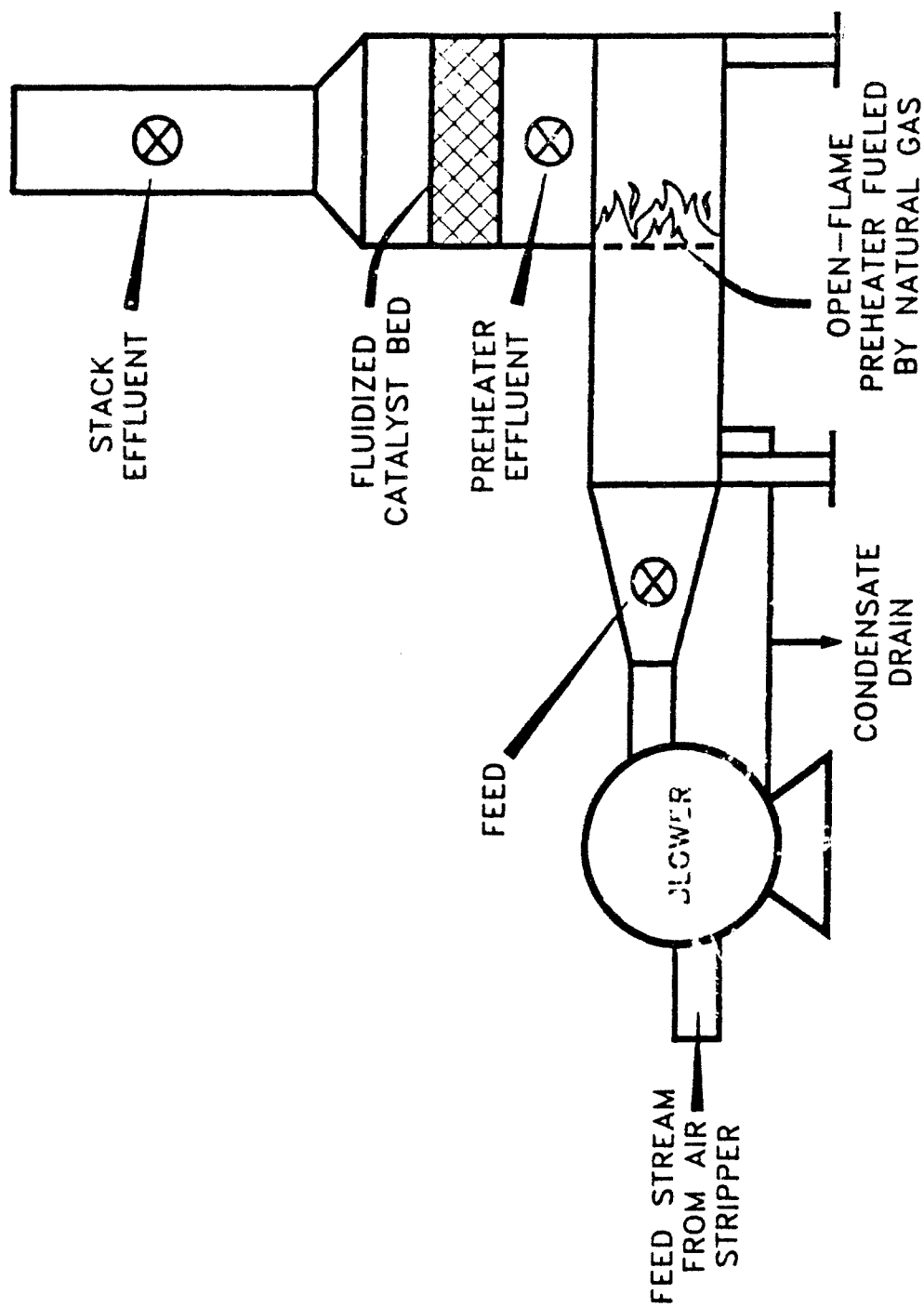


Figure 3. Schematic of Catalytic Oxidation Unit Showing Sampling Port Locations.

TABLE 2. SAMPLING PLAN FOR OXIDATION UNIT

DATE	CATALYST BED TEMPERATURE		SAMPLE PORT LOCATION		
	°C	°F	FEED	PREHEATER EFFLUENT	STACK
Oct. 1989	370	700	V	V	V
	425	800	V	V	V
	480	900	V,R	V,R	V,R
Feb. 1990	370	700	V	NS	V
Aug. 1990	315	600	V	V	V
	370	700	V	V	V
	425	800	V,Tol	V,Tol	V,G,Tol
May 1991	370	700	V,TCE	V,TCE	V,TCE

V = VOST Sample
 R = RTI Sample for HCl and Cl₂
 Tol = VOST Sample Collected While Toluene Spike Added to Feed Stream
 TCE = VOST Sample Collected While TCE Spike Added to Feed Stream
 G = Tedlar® Bag Sample
 NS = Not Sampled

that toluene was present in the feed stream at low concentrations. It was theorized that benzene may be a PIC formed from the destruction of toluene. To test this theory, the feed stream was spiked with toluene and VOST samples were collected while operating at a catalyst bed temperature of 425°C. Samples were collected at two different spiked feed concentrations of toluene. After completion of this sampling series, fresh catalyst was added to bring the bed depth up to the recommended bed depth of 8 inches. This was the first catalyst to be added after the initial charge in 1987.

The May 1991 series of samples obtained a final set of samples from the oxidation unit at the normal catalyst bed temperature (370°C). In addition, the feed stream was spiked with additional TCE, and VOST samples were collected while operating at a catalyst bed temperature of 370°C. These samples were collected at two different spiked feed stream concentrations of TCE.

B. VOST SAMPLING

The VOST is the EPA's Method 30 for the collection of volatile principal organic hazardous constituents from the stack gas effluents of hazardous waste incinerators. Volatile principal organic hazardous constituents are defined as those organic hazardous constituents with boiling points less than 100°C (Reference 5). The major emphasis of this project was VOST sampling. These samples were collected to determine the concentration of the VOCs in the air stream at all three sampling locations. The VOSTs were procured from Nutech Corporation.

Figure 4 is a flow diagram of a VOST. The VOST collects air samples through a heated, glass-lined probe to prevent condensation in the sample line. The air stream is passed through an ice-water-cooled condenser and then passed through a Tenax® resin trap. The VOCs in the air stream adsorb on the Tenax® resin. After passing through the resin trap, the air is directed to a condensate trap to remove condensed moisture that may have formed during the cooling of the air sample. The sample is then passed through a second condenser, which is similarly cooled, and to a second resin trap. The second trap, which contains Tenax® and activated carbon, serves as a backup trap in case the first trap is overloaded with VOCs or a compound was not selectively adsorbed by the Tenax® resin. After contact with the second trap, the air sample is passed through a rotameter to monitor the sampling rate, a vacuum pump, and a dry gas meter to determine the volume of gas sampled. A replicate sample was taken at each sampling condition in case the original sample was destroyed during transit or to verify the results from the first set. The VOST traps were packed in dry ice and shipped to the International Technology Analytical Services (ITAS) in Cincinnati, Ohio, where they were thermally desorbed and analyzed by gas chromatography/mass spectrometry.

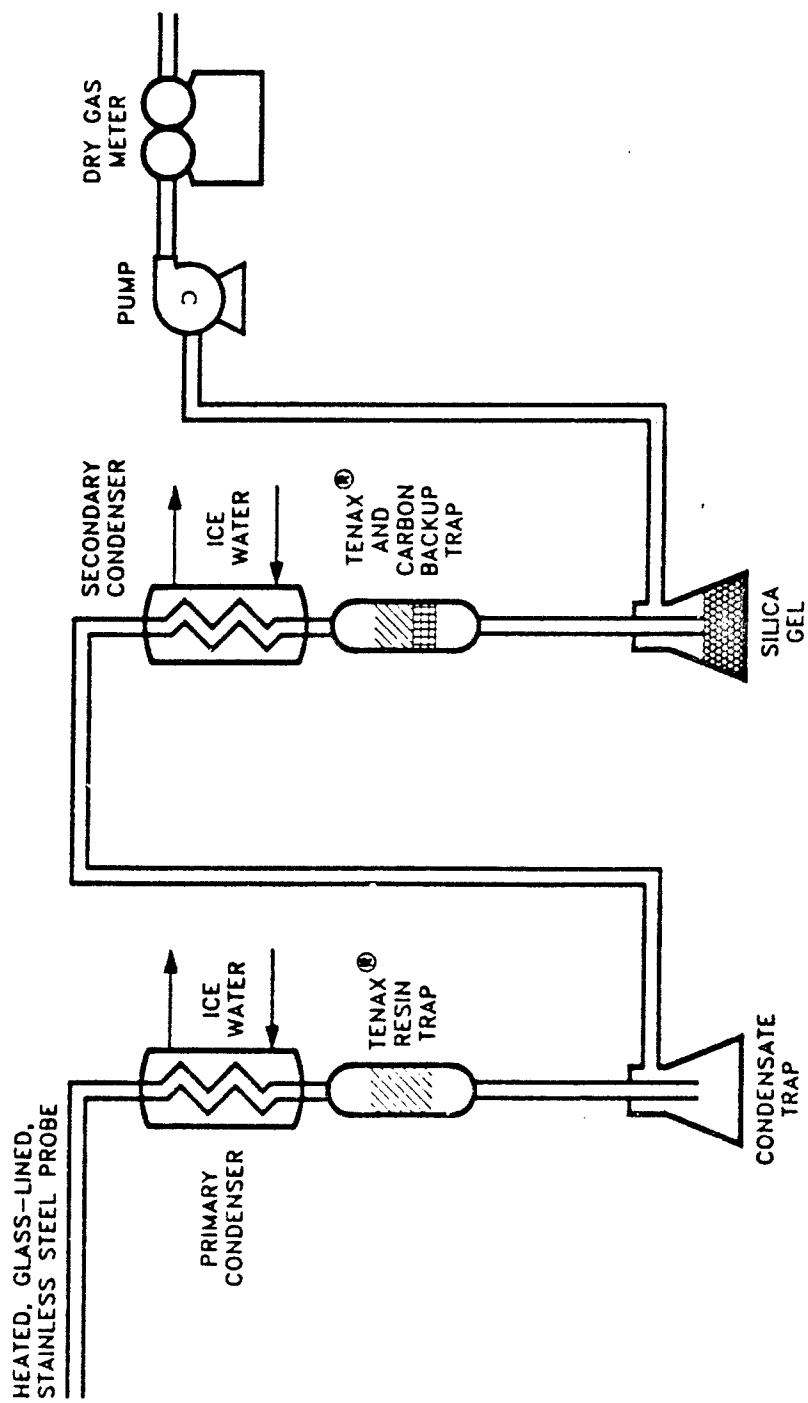


Figure 4. Flow Diagram of Volatile Organic Sampling Train (VOST).

(GC/MS). It was anticipated that the concentration of the feed samples would cause an overload of the GC detector when the trap was subjected to thermal desorption during the analysis procedure; therefore, the feed samples were packed similarly, but shipped to the ITAS laboratory in Knoxville, Tennessee, for analysis by a method involving desorption of the VOCs from the resin by methanol extraction and subsequent analysis by GC/MS. Based on the results from the first sampling series, it was decided to send the feed samples from the remaining sampling series to the Cincinnati laboratory for analysis by the thermal desorption method.

Field blank samples were taken at least once during the sampling day to determine whether the traps were susceptible to outside contamination while installing and removing the traps from the sample train. Trip blanks were also sent with each shipment to the laboratory to determine whether the samples were contaminated during the transportation to the laboratory.

Standard gas samples were obtained from a compressed gas cylinder of 5.4 $\mu\text{g/liter}$ (1.0 ppmv) TCE in nitrogen gas procured as a primary standard from Matheson Gas Products. In practice, it was necessary to transfer gas from the compressed gas to a Tedlar® bag to be able to control the sample flow rate to the VOST. After collecting the standard gas in the Tedlar® bag, a special connector was prepared to connect the Tedlar® bag to the VOST sample probe. VOST samples were collected from the Tedlar® bag using the same procedure as obtaining a sample from the oxidation unit.

C. HCl/Cl_2 SAMPLING

RTI was subcontracted to collect and analyze samples for HCl and Cl_2 . This was the first field test of a new method developed by RTI for the determination of these components in stack gas samples. Since their method was still considered experimental, it was decided to obtain samples at only one catalyst bed temperature. The RTI method involved pulling a gas sample through a heated, glass-lined probe and Teflon® tubing into a triple-impinger system. The first two impingers each contained 15 mL of 0.1N H_2SO_4 and the third impinger contained 15 mL of 0.1N NaOH. The solutions were analyzed by ion chromatography to quantify the amount of chlorine absorbed by the solutions. Three trains were operated in parallel at each sampling port to determine the precision of the method.

D. TEDLAR® BAG SAMPLING

Samples were collected from the stack effluent in Tedlar® bags while controlling the catalyst bed temperature at 425°C (800°F). The purposes of these samples were (1) to determine whether any VOCs, particularly chlorinated VOCs, were passing through the VOST without adsorbing to the Tenax® resin or activated carbon; and (2) to compare the data obtained to the data obtained from the VOST samples.

The bag samples were collected by passing the sample through the VOST and collecting the sample into the bag at the dry gas meter discharge (see Figure 4). During this sampling process, empty resin traps were installed in the VOST. Two replicate samples were collected and shipped to ITAS in Cincinnati for analysis by GC/MS.

E. MEASUREMENT OF AIR FLOW RATE

The velocity of air to the catalytic oxidation unit was measured in the duct to the incinerator blower with a hot-wire anemometer (Omega-Flo Model HH-615). The measured velocity was converted to a volumetric flow rate by multiplying the velocity by the cross-sectional area of the duct. The volumetric flow rate in the preheater effluent and stack effluent was assumed to be the sum of the flow rate of air entering the unit and the average flow rate of natural gas used for preheating the air stream. The natural gas flow rate was measured by the gas meter installed for determining the monthly usage of natural gas by the building.

SECTION III

RESULTS

Three types of destruction efficiency were determined from the samples obtained: (1) preheater destruction efficiency (PDE), (2) catalyst bed destruction efficiency (CDE), and (3) overall destruction efficiency (ODE). The equations used for calculating these results are shown in Equations (2) through (4), respectively.

$$PDE = \frac{M_F - M_P}{M_F} \times 100 \quad (2)$$

$$CDE = \frac{M_P - M_S}{M_P} \times 100 \quad (3)$$

$$ODE = \frac{M_F - M_S}{M_F} \times 100 \quad (4)$$

where

M_F = mass of component in feed

M_P = mass of component in preheater effluent

M_S = mass of component in stack effluent

TCE was the component for the destruction efficiency results presented.

A. SERIES 1

1. VOST Results - Feed

The results from the first series of VOST sampling, which are shown in Table 3, indicated that TCE was the only VOC in the feed stream. Periodic water samples taken by Wurtsmith personnel indicated that 1,2-dichloroethylene (DCE) was also a contaminant in the feed water to the air strippers. It is suspected that DCE was present in the feed stream, but its concentration was less than the detection limit for the methanol extraction method. The TCE concentration in the feed stream to the oxidation unit, which is independent of the temperature of the catalyst bed, ranged from 6.0 to 12 $\mu\text{g/liter}$ with an average of 8.6 $\mu\text{g/liter}$. It is believed that the sample that indicated the feed stream concentration was 12 $\mu\text{g/liter}$ is the correct analysis. This is supported by results from the water samples collected by Wurtsmith AFB personnel that estimated the concentration of TCE in the feed stream to the oxidation unit should be approximately 11 to 12 $\mu\text{g/liter}$ (see Figure 2).

TABLE 3. RESULTS FROM THE FIRST SERIES OF SAMPLING

COMPONENT	CATALYST BED TEMPERATURE (°C) (°F)		CONCENTRATION OF COMPONENTS		
			FEED ^a (μg/L)	PREHEATER ^b (μg/L)	STACK ^b (μg/L)
Trichloroethylene (TCE) [*]	370	700	7.8	5.8	0.071
	425	800	6.0	4.8	0.065
	480	900	12.0	2.3	0.051
1,2-Dichloroethylene	370	700		0.082	0.0007
	425	800		0.054	0.0007
	480	900		0.022 ^c	0.0006
Benzene	370	700		0.013 ^c	0.21
	425	800			0.35 ^d
	480	900		0.0092 ^c	0.19
Toluene [*]	370	700			0.0076
	425	800			0.0027
	480	900		0.011	0.0071
2-Butanone [*]	370	700			0.0028
	425	800			0.0026
	480	900			0.0012
1,1,1-Trichloroethane	370	700			0.0025
	425	800			0.0017
	480	900			0.0022
Trichlorofluoromethane [*]	370	700		0.096	0.071
	425	800			0.019
	480	900			0.015
Ethylbenzene	370	700			0.0058
	425	800			0.0009
	480	900			0.0014

TABLE 3. RESULTS FROM THE FIRST SERIES OF SAMPLING (CONCLUDED)

COMPONENT	CATALYST BED TEMPERATURE (°C) (°F)		CONCENTRATION OF COMPONENTS		
			FEED ^a (μg/L)	PREHEATER ^b (μg/L)	STACK ^b (μg/L)
Styrene	370	700			0.0079
	425	800			
	480	900			0.0005
Dichlorodifluoromethane	370	700			0.0049
	425	800			0.0052
	480	900			0.0045
Acetone ^c	370	700			0.043
	425	800			0.0081
	480	900			0.0047

^aFeed samples were analyzed by methanol extraction technique.

^bPreheater effluent and stack effluent samples were analyzed by thermal desorption technique.

^cThe quantity of this compound loaded on the VOST trap was estimated by the ITAS laboratory. Mass spectral data indicated the presence of the compound, but the result was less than the specified detection limit. Therefore this concentration is estimated.

^dThe quantity of this compound detected in this sample was above the linear range of the instrument. The analytical laboratory provided an estimated quantity. The concentration shown is estimated based on the analytical result.

^eThe presence of this compound was identified in a field blank sample taken during the sampling day.

2. VOST Results - Preheater Effluent

The preheater effluent sample results, also shown in Table 3, indicated that partial destruction of the TCE occurred in the preheater. As determined from Equation (2), the results indicated PDEs of 25 percent at 370°C (700°F), 20 percent at 425°C (800°F), and 81 percent at 480°C (900°F). A relationship should exist between the PDE and the catalyst bed temperature because the preheater exit temperature increases with the catalyst bed temperature. Therefore, the results should indicate an increased PDE as the catalyst bed temperature increased. A possible explanation for the apparently lower PDE at 425°C is that the measured TCE concentration in the feed sample was low when the catalyst bed was at 425°C. If it is assumed that the feed concentration was actually 12 µg/liter, as indicated by the feed stream sample at 480°C and the predicted concentration from water sample results, then the results indicated PDEs of 52 percent at 370°C, 69 percent at 425°C, and 81 percent at 480°C.

As shown in Table 3, some additional compounds were identified in this stream. As defined earlier, these compounds are PICs since TCE was the only compound identified in the feed stream; however, as previously mentioned, it is believed that DCE was present in the feed stream and is not a true PIC. The quantities of TCE and DCE combined represented greater than 98 percent of the contaminant mass detected in the preheater effluent samples. DCE and toluene were identified in later sampling series in low concentrations in the feed stream. Compounds identified in field blank samples are marked with an asterisk (*) on the component name in the table to show the presence of this compound may be caused by contamination while installing and removing the VOST traps.

3. VOST Results - Stack Effluent

Results from the stack effluent samples, also shown in Table 3, demonstrate that the catalyst was effectively destroying the TCE. The oxidation unit exhibited greater than 99 percent ODE of TCE at each catalyst bed temperature tested. Since the stack samples were anticipated to be much lower in concentration, they were analyzed at a high sensitivity level and several more PICs were identified in the stack sample. These PICs are identified in Table 3. Initially the formation of benzene was puzzling, but information obtained later indicated that methane undergoes a series of reactions to form ethyne (acetylene). Ethyne, in turn, undergoes a series of reactions which may form benzene (Reference 3). At least three of the components identified in the stack effluent may be explained by the presence of these compounds in either the field blank or trip blank; these are identified with an asterisk on the component name.

A GC/MS library search was performed on the stack effluent samples to identify any compounds which appeared in the GC analysis but were not identified, because they were not on the list of compounds requested. The presence of oxychlorinated compounds was of particular interest. This library search did not identify any additional chlorinated species. All tentatively identified compounds were very low in concentration (less than or equal to $0.02 \mu\text{g/Liter}$ for any particular compound and less than or equal to $0.03 \mu\text{g/Liter}$ for the total contribution of the compounds to any sample). It should be noted that the concentration values were estimated by ITAS. Hexane was identified in one of the stack samples ($0.002 \mu\text{g/Liter}$), but it was the only compound name identified. The other tentatively identified compounds were typically labelled as "alkane", "C-6 alkane", "C-7 alkane", "C-9 alkane", "C9-11 alkane", or "hydrocarbon". ITAS personnel have stated that oxychlorinated compounds are hard to identify through a library search, and they are usually identified as "unknown".

4. RTI Results - Series 1

Equation (1) indicates that one mole of Cl_2 and one mole of HCl are formed for each mole of TCE reacted during the complete oxidation of TCE. The samples collected by RTI for the determination of HCl and Cl_2 were obtained when the catalyst bed temperature was 480°C (900°F). The results from the analyses are presented in Table 4. According to RTI, the concentration of Cl^- in the H_2SO_4 impinger indicated the concentration of HCl in the gas stream, and the concentration of Cl^- in the NaOH impinger indicated the concentration of Cl_2 in the gas stream. A copy of the RTI report is attached as Appendix A.

The results from the samples collected from the feed stream indicated only negligible amounts of HCl and/or Cl_2 in the feed. Chlorine gas is continuously added to the water feed stream to the stripping column (0.5 pound Cl_2/day) to control bacterial growth in the column. These results indicate that the chlorine is not removed by the air stripping and has no impact on the oxidation unit's performance.

Samples from the preheater effluent showed that the Cl^- concentration (as HCl) was $3.8 \mu\text{g/liter}$, and there was a negligible quantity of Cl_2 . From a material balance of the TCE in the feed samples and the preheater effluent samples, the expected HCl concentration was $3.0 \mu\text{g/liter}$ and the expected concentration of Cl_2 was $5.8 \mu\text{g/liter}$ based on the relationship identified in Equation (1).

Samples taken from the stack effluent did not indicate any measurable HCl or Cl_2 . This was considered highly unusual since the VOST results indicated that most of the halogenated organic compounds in the feed were destroyed.

TABLE 4. RESULTS FROM SAMPLES FOR DETERMINATION OF HCl AND Cl₂^a

Position	Train Number	H ₂ SO ₄ Impinger #1 (Total µg/mL Cl ⁻)	H ₂ SO ₄ Impinger #2 (Total µg/mL Cl ⁻)	NaOH Impinger (Total µg/mL Cl ⁻)
Feed	1	1.11	ND	0.3
	2	0.6	ND	ND
	3 (Spike) ^b	4.64	ND	ND
Preheater Effluent	1	30.8	ND	ND
	2	31.7	0.8	0.9
	3 (Spike) ^b	0.6 ^c	ND	ND
Stack Effluent	1	1.1	ND	ND
	2	4.3	ND	ND
	3 (Spike) ^b	20.8	ND	ND

^aResults are from report by RTI (see Appendix).

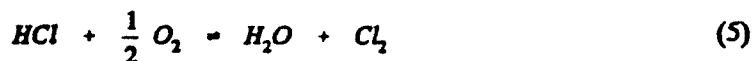
^bThe concentration of the spike was 3.62 µg/mL Cl⁻.

^cThe pH of this sample was approximately 9; NaOH may have been used by mistake.

Additional Information

Blank H₂SO₄ = 0.8 µg/mL Cl⁻
 Blank NaOH = 0.5 µg/mL Cl⁻
 ND = Not Detected

A possible explanation for the absence of Cl_2 is the Deacon reaction shown in Equation (5) (Reference 1).



As written, the Deacon reaction is exothermic at room temperature. In the presence of high temperatures, the reaction would favor the reaction of water with chlorine to yield HCl and oxygen. However, this explanation implies that two moles of HCl are formed for each mole of TCE destroyed. A material balance based on this explanation would indicate that the concentration of HCl would be 6.0 $\mu\text{g/liter}$ in the preheater effluent and 7.2 $\mu\text{g/liter}$ in the stack effluent.

Another possibility for the absence of Cl_2 is that the chlorine species may be reacting on the surface of the catalyst granules to form inorganic compounds. These compounds are then attrited from the surface of the granules and escape through the stack effluent; however, calculations have shown that the quantity of chlorine unaccounted for is much higher than the quantity of catalyst lost by attrition. Therefore, this does not seem to be a feasible possibility to account for the missing chlorine.

One other possibility for the absence of Cl_2 is the formation of oxychlorinated compounds in the preheater and/or the catalyst bed. The oxychlorinated compounds were either not adsorbed by the Tenax[®]/carbon traps or these compounds were not identified by the GC/MS analyses.

B. SERIES 2

The February 1990 series of VOST samples was collected only at one catalyst bed temperature (370°C), and the samples were obtained only from the feed and the stack effluent. The results from this series of sampling are shown in Table 5. None of the components identified in Table 5 were identified in the field blank or trip blank samples.

1. Feed

The quantity of TCE collected on the VOST trap exceeded the linear range of the analytical detection limit, but the ITAS provided an estimate of the amount of TCE present. They estimated the quantity of TCE in the sample by two methods: (1) major ion method and (2) minor ion method. The major ion method estimated the TCE concentration as 2.2 $\mu\text{g/liter}$, and the minor ion method estimated the concentration of TCE as 11.8 $\mu\text{g/liter}$. The latter estimate is believed to be the more appropriate estimate, based on an evaluation of water sample results that estimated the concentration would be approximately 10 $\mu\text{g/liter}$ (See Figure 2). Although the instrument's calibration was too

TABLE 5. VOST RESULTS FROM SERIES 2

COMPONENT	FEED ($\mu\text{g/L}$)	STACK ($\mu\text{g/L}$)	DESTRUCTION EFFICIENCY (%)
Trichloroethylene (TCE)	11.8 ^a	0.30 ^a	97
Benzene	0.0044	0.10 ^b	-2060 ^c
Toluene	0.38	0.014	96
1,2-Dichloroethene	0.30	0.0015	99
Trichlorofluoromethane	0.0048	0.0085	-77 ^c
1,1,1-Trichloroethane	0.0026	ND	100
Chloroform	0.0036	0.0008	78

^aThe loading of TCE on the traps exceeded the linear range of the analytical instrument for the feed and stack samples. Values are estimated as explained in text.

^bThe loading of benzene on the traps exceeded the linear range of the analytical instrument for the stack sample. Stack concentration value is estimated as explained in text.

^cA negative value indicates a concentration increase in that component.

sensitive to quantify the amount of TCE, small quantities of DCE, toluene, benzene, and other components were also detected in the feed. These compounds, which were not found in the feed stream during the first series of sampling, probably would not have been detected during this series if the instrument had been calibrated to a lower sensitivity.

2. Stack

As indicated in Table 5, the stack sample was analyzed at a calibration level that was also too sensitive to quantify the amount of TCE, but the analytical laboratory provided a best estimate. Based on the analytical laboratory's TCE feed and stack estimates, the TCE was destroyed at an overall efficiency of 97 percent. All the VOCs except benzene showed very good destruction rates. The presence of toluene in the feed stream prompted the theory that benzene was a PIC formed from the destruction of toluene. This set of results indicated that the molar quantity of toluene present in the feed sample is more than twice the molar quantity of benzene seen in the stack sample. The formation of benzene from the destruction of toluene seemed more plausible than from the destruction of TCE; however, benzene and other PICs may have been formed by mechanisms such

as those cited earlier. Although the destruction efficiency was high, the concentration of TCE in the stack effluent increased from 0.071 $\mu\text{g/liter}$ in October 1989 to 0.30 $\mu\text{g/liter}$ in February 1990. This signified that (1) the catalyst may be losing some effectiveness, (2) the catalyst bed needed replenishment, or (3) this analysis was too high.

C. SERIES 3

The objectives of the third series of samples were (1) to obtain more data on destruction efficiency versus catalyst bed temperature, (2) to evaluate the effect of spiking the feed stream with toluene, (3) to obtain a sample of TCE (1.0 ppm in nitrogen) from a compressed gas cylinder for analysis, and (4) to obtain Tedlar® bag samples from the stack effluent. The results from these tests are discussed below, and the data from the first two objectives are shown in Table 6. The Tedlar® bag data are shown in Table 7.

1. Normal VOST Samples - Series 3

a. Feed

The results, which are shown in Table 6, indicated that TCE was still the primary contaminant, but the data indicated small quantities of DCE, benzene, toluene, and 2-butanone were also present in the feed stream. The measured TCE concentration of the feed to the oxidation unit ranged from 9.7 to 15.0 $\mu\text{g/liter}$ with an average of 13.3 $\mu\text{g/liter}$. The results from the water samples taken by Wurtsmith personnel estimated the concentration of TCE to be approximately 8 $\mu\text{g/liter}$ during this time period (see Figure 2). The concentration of 1,2-DCE ranged from 0.11 to 0.15 $\mu\text{g/liter}$. The concentrations of benzene, toluene, and 2-butanone in the feed stream were sporadic. The variation of the toluene and 2-butanone may be rationalized by the presence of these compounds on the field blank or the trip blank samples. These compounds are identified in Table 6 with an asterisk on the component name. Most of the attention for this series of samples will be focused on TCE and DCE.

b. Preheater Effluent

The preheater effluent results for TCE, which are also shown in Table 6, indicated the preheater exhibited destruction efficiencies of 45 percent at 315°C, 68 percent at 370°C, and 77 percent at 425°C. An analysis of the DCE results indicates PDEs of 58 percent at 315°C, 72 percent at 370°C, and 75 percent at 425°C.

The anomalous behavior of the results for toluene and 2-butanone are plausibly due to contamination during installing and removing VOST traps from the sampling train.

TABLE 6. RESULTS FROM THE THIRD SERIES OF SAMPLING

COMPONENT	CONDITIONS		CONCENTRATION OF COMPONENTS		
	Temp (°C)	Spike Additions ^a	FEED (µg/L)	PREHEATER (µg/L)	STACK (µg/L)
Trichloroethylene (TCE)	315	None	15.0 ^b	7.8	0.83
	370	None	13.5 ^b	4.5	0.37
	425	None	14.6 ^b	3.2	0.17
	425	1	13.5 ^b	3.6	0.18
	425	2	9.7	2.5	0.15
1,2-Dichloroethylene	315	None	0.15	0.057	0.0051 ^c
	370	None	0.11	0.038	0.0019 ^c
	425	None	0.15	0.021	ND
	425	1	0.14	0.036	ND
	425	2	0.13	0.015 ^c	ND
Benzene	315	None	0.002 ^c	0.0032 ^c	0.037
	370	None	ND	0.0034 ^c	0.0045 ^c
	425	None	ND	ND	0.0061 ^c
	425	1	ND	0.0078 ^c	0.015
	425	2	ND	0.0051 ^c	0.0095
Toluene [*]	315	None	0.012 ^c	0.14	0.67
	370	None	0.027	0.038	0.30
	425	None	ND	0.38	0.042
	425	1	0.46	0.057	ND
	425	2	0.89	0.042	0.017
2-Butanone [*]	315	None	ND	0.14	0.67
	370	None	0.49	0.070	0.43
	425	None	0.087	0.70	0.045
	425	1	0.46	0.11	0.026
	425	2	0.38	ND	0.030

TABLE 6. RESULTS FROM THE THIRD SERIES OF SAMPLING (CONCLUDED)

COMPONENT	CONDITIONS		CONCENTRATION OF COMPONENTS		
	Temp (°C)	Spike Additions ^a	FEED (µg/L)	PREHEATER (µg/L)	STACK (µg/L)
1,1,1-Trichloroethane	315	None	0.0053 ^c	0.0074 ^c	0.0039 ^c
	370	None	ND	0.0040 ^c	0.0020 ^c
	425	None	0.0042 ^c	0.0072 ^c	ND
	425	1	0.0061 ^c	0.017 ^c	ND
	425	2	0.0044 ^c	ND	ND
Chloroform	315	None	0.0057 ^c	0.010 ^c	0.0077 ^c
	370	None	0.0042 ^c	0.0047 ^c	0.0065 ^c
	425	None	0.0065 ^c	0.020	0.0022 ^c
	425	1	0.0059 ^c	ND	0.0050 ^c
	425	2	0.0063 ^c	ND	0.0028 ^c
Ethylbenzene	315	None	ND	ND	0.0071 ^c
	370	None	ND	ND	ND
	425	None	ND	0.0006	ND
	425	1	ND	ND	ND
	425	2	ND	ND	ND

^a"None" means that the feed stream to the incinerator was not spiked with additional toluene. "1" means that the feed stream was spike with toluene to increase the toluene concentration by approximately 0.45 µg/liter. "2" means that the feed stream was spiked with toluene to increase the toluene concentration by approximately 0.90 µg/liter.

^bThe quantity of this compound detected in this sample was above the linear range of the instrument. The analytical laboratory provided an estimated quantity. The concentration shown is estimated based on the analytical result.

^cThe quantity of this compound loaded on the VOST trap was estimated by the laboratory. Mass spectral data indicated the presence of the compound, but the result was less than the specified detection limit. Therefore this concentration is also estimated.

^dThe presence of this compound was identified in a field blank taken during the sampling day.

TABLE 7. DATA FROM TEDLAR® BAG SAMPLES FROM STACK EFFLUENT

Compound	Gas Bag 1 (µg/liter)	Gas Bag 2 (µg/liter)
Trichloroethylene (TCE)	0.07	0.06
1,1-Dichloroethylene	0.04	0.02
1,1,1-Trichloroethane	0.95	0.5
Carbon Tetrachloride	0.008	0.004
Benzene ^a	0.003	0.003
Toluene ^a	0.60	0.55
4-methyl-2-pentanone	0.05	0.04
Tetrachloroethylene ^a	0.003	0.003
Chlorobenzene	0.02	0.02
Ethylbenzene	0.045	0.041
Styrene	0.07	0.12
Total Xylenes	0.31	0.31
Chloroform	0.005	ND ^b

^aValues shown are estimated. The mass spectral data indicated the presence of the compound, but the result is less than the detection limit.

^bND = Not Detected

c. Stack Effluent

The stack effluent results, which are displayed in Table 6, indicated an ODE of 94 percent at 315°C, 97 percent at 370°C, and 99 percent at 425°C for TCE. The ODE for TCE at 370°C compares with the ODE for TCE found in the February 1990 sampling series. Slightly better ODEs were found for DCE.

These results indicated that the concentration of TCE in the stack effluent was comparable to the concentration found in the February 1990 series of sampling when compared at the same catalyst bed temperature. However, this is still an increase in TCE concentration since the October 1989 sampling.

2. Toluene-Spiked Feed Stream Sample Results - Series 3

After obtaining the samples from the catalytic oxidation unit at the three different catalyst bed temperatures, toluene was added to the feed stream while maintaining the catalyst bed temperature at 425°C. VOST samples were collected while spiking the feed at two different toluene concentrations. The toluene gas used for spiking the feed stream was purchased from Matheson Gas Products as a certified standard gas with a toluene concentration of 2420 µg/liter (643 ppm). The flow rate of the spike gas was controlled at 6 liters/minute to increase the toluene concentration in the feed stream by approximately 0.45 µg/liter in the first set. The flow rate of the spike gas was controlled at 12 liters/minute to increase the toluene concentration in the feed stream by approximately 0.90 µg/liter in the second set. The results obtained from spiking the stream with toluene are displayed in Table 6 with the normal samples.

a. Feed

The data from the February 1990 sampling series indicated that toluene was present in very small quantities in the feed stream; however, the VOST results from the unspiked feed stream samples of this series indicated essentially no toluene present. The toluene-spiked samples confirmed that the concentration of toluene in the feed stream during this series was negligible, since the concentrations of toluene measured in the feed stream from the toluene-spiked samples were very close to the expected concentration of toluene if there had not been any toluene in the feed stream initially.

b. Preheater Effluent

The data obtained from the preheater effluent samples were similar to those obtained from normal VOST sampling except the toluene concentration decreased rather than increased. The preheater exhibited destruction efficiencies of 88 and 95 percent for toluene. The PDE for TCE was similar to normal operating conditions.

c. Stack Effluent

The concentration of TCE in the stack effluent compared very closely to the data obtained from operating the oxidation unit without a toluene spike, so the ODE for TCE was still approximately 99 percent at 425°C. The results also agreed with the unspiked set of samples taken at the catalyst bed temperature of 425°C showing that DCE was below detection limits in the stack effluent. Although the concentration of benzene in the stack effluent was slightly higher in the toluene-spiked samples versus the nonspiked samples, the results could not confirm a relationship between the concentration of toluene in the feed stream and the concentration of benzene in the stack effluent since the concentration of benzene decreased during the second set of toluene spikes.

3. Sample from Compressed Gas Cylinder - Series 3

As previously described, a standard gas sample was obtained from a compressed gas cylinder containing TCE in nitrogen gas to verify the sampling and analytical procedures. The analysis of this sample indicated that the concentration of TCE was 3.8 $\mu\text{g}/\text{liter}$, which is approximately 70 percent of the expected concentration. According to the VOST method, an analysis of this type must fall within plus or minus 50 percent of the accepted value (Reference 5). Therefore, this sample result meets this criteria.

4. Tedlar® Bag Sample Results

Replicate Tedlar® bag samples obtained from the stack effluent were analyzed to compare the data obtained to the data obtained from the VOST sampling and to determine if there were major compounds discharged through the stack that the Tedlar®/carbon traps were not adsorbing. The Tedlar® bag results, which are shown in Table 7, do not compare well with the results obtained from the VOST sampling. The Tedlar® bag results identified some compounds (e.g., carbon disulfide, chlorobenzene) which were not identified by the VOST sampling; however, only small quantities of these compounds were found and thus can not explain the fate of the chloride atoms.

Two potential problems have been identified with these samples results. First, the sample was acquired through the VOST and passed through the sampling pump and dry gas meter into the Tedlar® bag. It is plausible that contaminants adsorbed on the walls of the pump and meter during the process. Second, through a mixup in communications, the analytical laboratory desorbed the bag samples onto Tenax® prior to analysis. Therefore, it was unlikely to find any different compounds than those found through normal VOST sampling.

D. SERIES 4

The objectives of the fourth series of sampling were (1) to obtain data regarding the normal operation of the oxidation unit and (2) to evaluate the effect of spiking the feed stream with additional TCE. The results from this sampling effort are shown in Table 8. The designation of the samples in the table are as follows:

Because of the quantity of VOCs expected to be loaded on the VOST traps, ITAS deviated from the normal analysis procedure for VOST traps. Initially, ITAS desorbed all the VOST samples into canisters. Aliquots were taken from the canister and injected into the GC for analysis. Midway through this method, ITAS opted to load a portion of the gas from the canisters onto new VOST

TABLE 8. RESULTS FROM THE FOURTH SERIES OF SAMPLES

COMPONENT	CONDITIONS*	CONCENTRATION OF COMPONENTS		
		FEED ($\mu\text{g/L}$)	PREHEATER ($\mu\text{g/L}$)	STACK ($\mu\text{g/L}$)
Trichloroethylene (TCE)	Normal	7.7	3.7	ND
	TCE Spike 1	16.6	6.5	ND
	TCE Spike 2	17.4	7.3	0.075
Benzene	Normal	1.7	ND	0.32
	TCE Spike 1	ND	ND	0.21
	TCE Spike 2	ND	ND	0.23
Toluene*	Normal	5.1	ND	0.87
	TCE Spike 1	20	2.4	ND
	TCE Spike 2	5.8	ND	0.75
Xylenes	Normal	0.68	ND	ND
	TCE Spike 1	ND	ND	ND
	TCE Spike 2	ND	ND	ND

*"Normal" means that the feed stream to the incinerator was not spiked with additional TCE.

"TCE Spike 1" means that the feed stream was spiked with TCE to increase the TCE concentration by approximately 6 $\mu\text{g/liter}$. "TCE Spike 2" means that the feed stream was spike with TCE to increase the TCE concentration by approximately 12 $\mu\text{g/liter}$.

*Toluene was a contaminant present in the field blank sample.

traps and then analyze those traps according to the VOST protocol. The samples that were analyzed directly from the gas canister were the feed samples for Normal and Spike 1 conditions, the preheater samples for Normal and Spike 1 conditions, and the stack effluent sample for Normal conditions.

1. Normal VOST Samples - Series 4

a. Feed

The results from the feed sample taken at normal conditions (catalyst bed temperature was controlled at 370°C) indicated that TCE was still the primary contaminant, but small quantities of benzene and toluene were identified also. The measured TCE concentration of the feed to the

oxidation unit was 7.7 $\mu\text{g/liter}$. This result compares favorably with 6.0 $\mu\text{g/liter}$ predicted from the linear regression of data from Wurtsmith water samples (See Figure 2). The analytical results from the field blank samples indicated that toluene was a potential contaminant adsorbed during the changing of the traps.

b. Preheater Effluent

TCE and toluene were the only compounds detected in the preheater effluent sample. The PDE for TCE, which is determined from Equation (2), was 52.3 percent. The concentration of toluene was higher in the preheater effluent than the feed sample. This toluene concentration increase is most likely a result of contamination during installing and removing the VOST traps from the sampling train as revealed by the field blank samples.

c. Stack Effluent

The results from the stack effluent indicated that the concentration of TCE was below the limit of detection. If one assumes that the concentration was equal to the limit of detection, then the concentration of TCE would have been 0.25 $\mu\text{g/liter}$ which corresponds to an ODE of 95.5 percent. If one assumes that the concentration of TCE in the stack effluent was approximately the same as the concentration of TCE in the stack effluent from the second series of TCE-spiked samples, then the concentration could be assumed to be 0.075 $\mu\text{g/liter}$, which corresponds to an ODE of 98.7 percent.

2. TCE-Spiked Feed Stream Sample Results - Series 4

After obtaining the samples from the catalytic oxidation unit at the normal operating conditions, TCE was added to the feed stream while maintaining the catalyst bed temperature at 425°C. VOST samples were collected while spiking the feed at two different TCE concentrations. The TCE gas used for spiking the feed stream was procured from Matheson Gas Products. The spike gas was a certified standard gas with a TCE concentration of 30,000 $\mu\text{g/liter}$ (5600 ppmv). The flow rate of the spike gas was controlled at 5.8 liters/minute to increase the TCE concentration in the feed stream by approximately 6 $\mu\text{g/liter}$ in the first set. The flow rate of the TCE spike gas was controlled at 12 liters/minute to increase the TCE concentration in the feed stream by approximately 12 $\mu\text{g/liter}$ in the second set of samples.

a. Feed

The spike additions to the feed stream were successful in increasing the concentration of TCE in the feed stream as shown in Table 8. However, the concentration of TCE was slightly higher in the Spike 1 sample and slightly lower in the Spike 2 sample than planned. These differences are

probably due to variance in sample analysis. Toluene was found to be the most concentrated contaminant in the Spike 1 sample, but this was not observed in the Spike 2 sample. The cause of the high concentration of toluene can only be speculated, but one potential cause is that some toluene-rich contaminated water passed through the air stripper during this sampling period. It could also have been caused by contamination during changing of the VOST traps as shown potentially possible by the field blank samples. One other potential cause was some residual toluene on the VOST traps prior to their use.

b. Preheater Effluent

The analyses of the preheater effluent for the Spike 1 samples detected the presence of TCE and toluene. The PDE for TCE was 60.3 percent. The concentration of toluene in the preheater effluent was significantly less than detected in the feed stream.

The analyses of the preheater effluent during the second TCE spike indicated the PDE was 58 percent. The replicate of this particular sample was also analyzed for comparison purposes. The amounts of TCE, benzene, and toluene compared well between the two samples, but the first sample identified the presence of freon 113, methylene chloride, and 1,1,1-trichloroethane, whereas the second sample did not. However, these additional compounds that were found in the first sample were also found in the field blank samples. The source of these compounds is unknown, but the possibilities include (1) compounds from the feed stream (which are low enough in concentration in the feed stream that they are nondetectable in the feed stream samples) that escape through the condensate drains for the blower and catalytic oxidation unit (see Figure 3), (2) residual compounds that may have been left on the traps prior to use of the traps, or (3) the compounds may have entered as contaminants in the natural gas fuel for the preheater.

c. Stack Effluent

The concentration of TCE in the stack effluent of the Spike 1 samples was below the detection limit. If one again assumes that the concentration of TCE was equivalent to the limit of detection, then the concentration of TCE in the stack effluent was 0.11 $\mu\text{g/liter}$ and an ODE of 99.1 percent was obtained. However, the stack effluent sample from the Spike 2 samples had a lower limit of detection and the quantity of TCE was measured as 0.075 $\mu\text{g/liter}$. It is reasonable to assume that this measured concentration is comparable to the unmeasurable concentration in the Spike 1 sample. An ODE of 99.4 percent for the Spike 1 samples is obtained from this assumption. The results from the Spike 2 samples are straightforward and indicate an ODE of 99.6 percent.

3. Samples from Compressed Gas Cylinder - Series 4

As previously described, replicate gas samples were obtained from a compressed gas cylinder, which contained 5.45 $\mu\text{g/liter}$ (1.0 ppm) TCE in nitrogen gas, to verify methods. Both samples obtained were analyzed. The analyses of these samples indicated that the concentration of TCE was 3.0 $\mu\text{g/liter}$ which is approximately 55 percent of the expected concentration. According to the VOST protocol, an analysis of this type must fall within plus or minus 50 percent of the accepted value (Reference 5). Therefore, this sample result meets this criterion. One of the standard samples indicated that toluene was present and the other standard sample indicated that freon 113, methylene chloride, and 1,1,1-trichloroethane were present. All of these additional compounds were identified by the field blank samples also.

E. OVERALL ANALYSIS

The data obtained from the individual sampling series were compared in terms of catalyst bed temperature and sampling date. Table 9 and Figures 5 through 7 summarize the results from the four series of samples, using Equations (2) through (4) to determine the destruction efficiencies. The lines connecting the data points in these figures are drawn to show the data collected from a particular series and do not represent a statistical analysis of the data.

Figure 5 shows the results of the preheater destruction efficiency versus the catalyst bed temperature as a function of the sampling date. Since the samples of the preheater effluent were not collected in the February 1990 sampling series, the preheater and catalyst bed destruction efficiencies could not be determined for that series. The October 1989 series and the August 1990 series show that the PDE increased as the catalyst bed temperature was increased. This was expected since the preheater exit temperature increased with the catalyst bed temperature. It was anticipated that the performance of the preheater would remain approximately constant from one series to another, but Figure 5 appears to indicate otherwise. It is believed that the difference in the October 1989 series and August 1990 series shown in Figure 5 can be attributed to sample analysis variance.

Figure 6 displays the results of the catalyst bed destruction efficiency versus the catalyst bed temperature as a function of the sampling date. The October 1989 series of samples indicated essentially no benefit gained from operating the catalytic oxidation unit at the catalyst bed temperatures higher than the ARI recommended temperature; however, the August 1990 series indicated there was a relation between the CDE and the catalyst bed temperature. The major difference in the results from these two series is likely attributable to the loss of catalyst by attrition.

TABLE 9. SUMMARY OF DATA FOR TRICHLOROETHYLENE (TCE)

Sampling Date	Catalyst Bed Temp. (°C)	TCE Concentration (µg/L)			Destruction Efficiency (%)		
		Feed	Preheater	Stack	Preheater	Catalyst Bed	Overall
October 1989	370	12	5.8	0.071	51.7	98.8	99.4
	425	12	4.8	0.065	60.0	98.6	99.5
	480	12	2.3	0.051	80.8	97.8	99.6
February 1990	370	11.5	NA*	0.29	NA*	NA*	97.5
August 1990	315	14	7.8	0.83	44.7	89.4	94.1
	370	14	4.4	0.36	68.8	91.8	97.4
	425	14	3.2	0.16	77.3	95.0	98.9
	425 (Tol. Spike)	14	3.1	0.17	78.0	94.5	98.8
May 1991	370	5.7	2.7	0.075	52.3	97.2	98.7
	370 (TCE Spike 1)	12	4.7	0.075	60.3	98.4	99.4
	370 (TCE Spike 2)	17	7.3	0.075	58.2	99.0	99.6

*NA = Not Available: The preheater effluent was not sampled during the February 1990 sampling series.

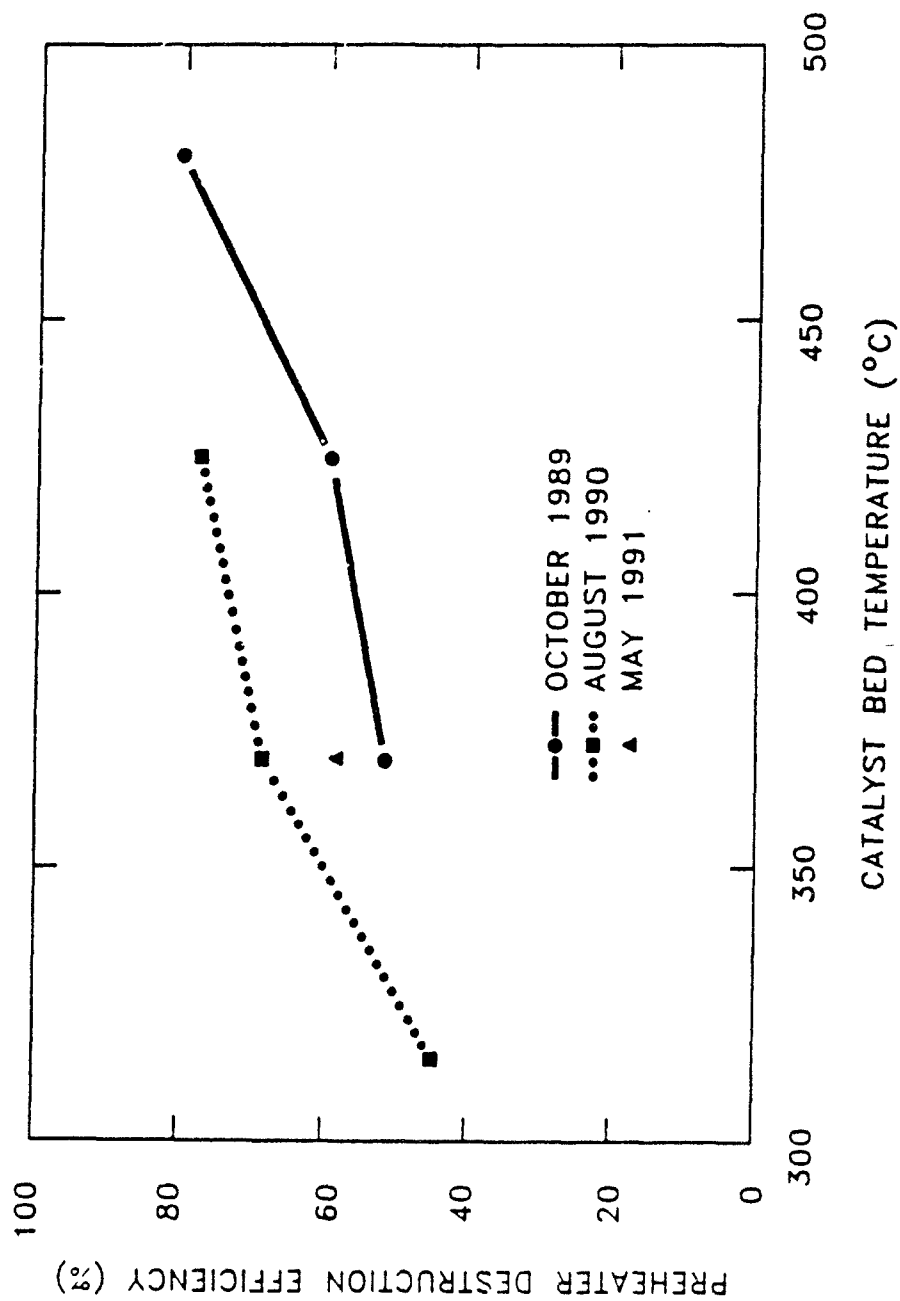


Figure 5. Preheater Destruction Efficiency Versus Catalyst Bed Temperature.

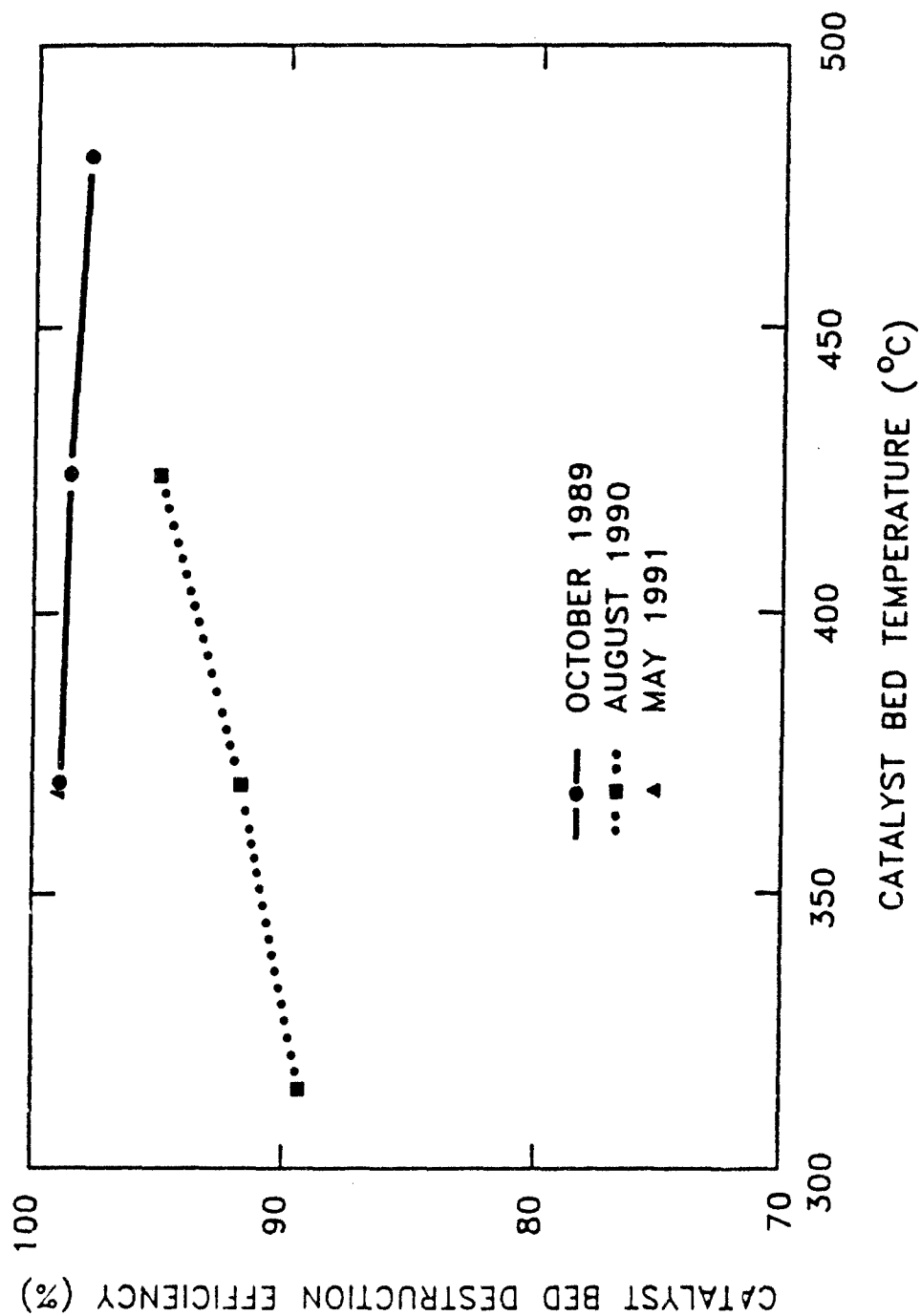


Figure 6. Catalyst Bed Destruction Efficiency Versus Catalyst Bed Temperature.

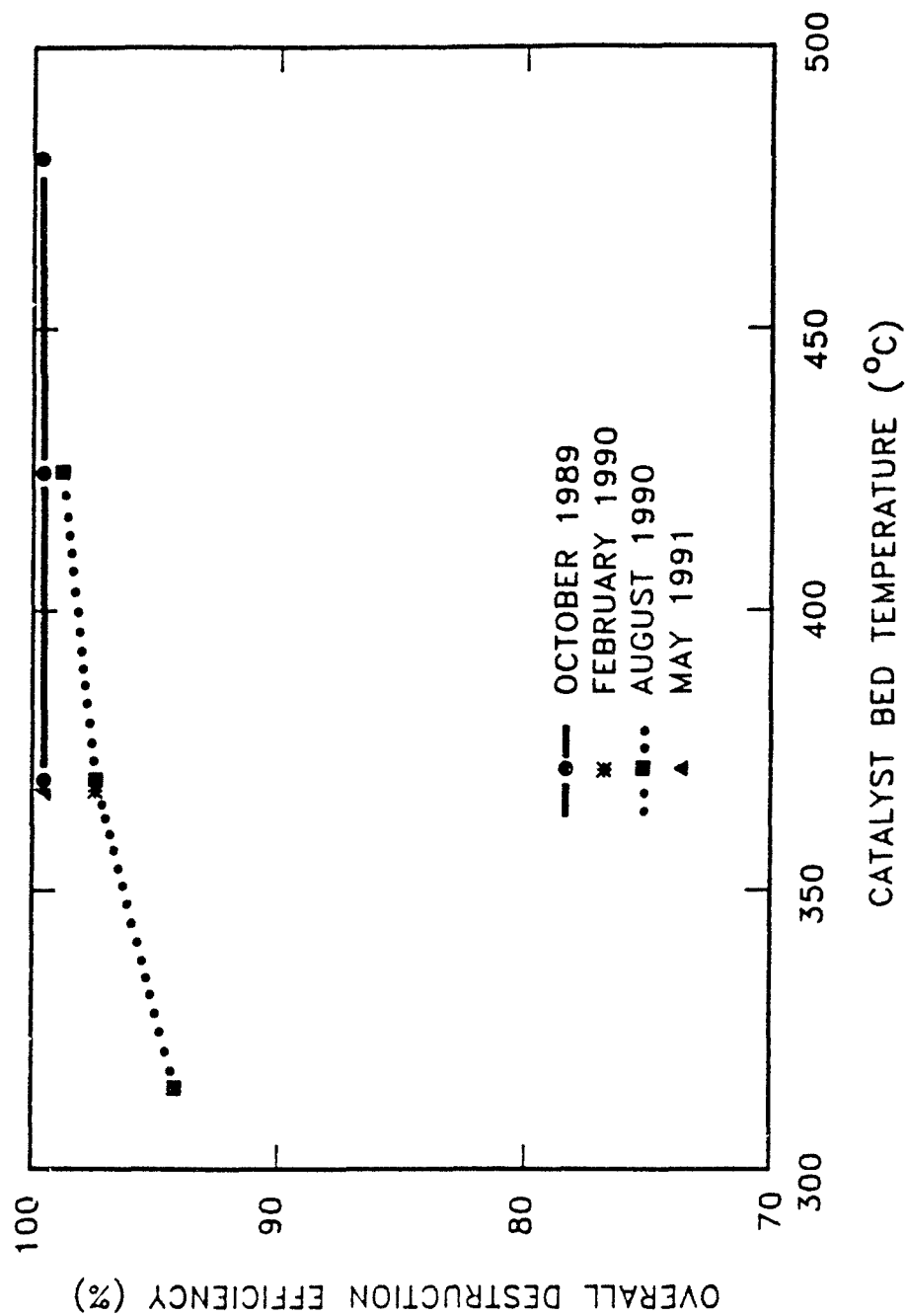


Figure 7. Overall Destruction Efficiency Versus Catalyst Bed Temperature.

The depth of the catalyst bed had decreased from 19 cm (7.5 inches) in October 1989 to 15.9 cm (6.25 inches) in the August 1990 series. These depths were determined by the correlation of the differential pressure across the catalyst bed to the bed depth. Attrition of the catalyst causes a decrease of the residence time (or an increase in the space velocity) of the air stream through the catalyst bed. The May 1991 samples were collected when the catalyst bed depth was approximately 21 cm (8.35 inches) and Figure 6 shows that the CDE returned to approximately 98 percent after replenishing the catalyst bed.

Figure 7 shows the ODE with the same parameters as Figures 5 and 6. The behavior of the ODE is similar to that of the CDE in Figure 6. Figure 7 shows that the ODE was approximately 97 percent at 370°C when the unit contained the smaller quantity of catalyst. The ODE of the unit at 315°C (600°F) was just under 95 percent. The ODE returned to approximately 99 percent after replenishing the catalyst bed for the May 1991 series.

The data indicated that the concentration of the contaminants in the stack effluent was increasing with time until the catalyst bed was replenished. This concentration increase was likely caused by: (1) a decrease in the catalytic activity and/or (2) a smaller amount of catalyst present. The latter is believed to be the more plausible reason for an increase in contaminant concentration in the stack effluent. As shown in Table 1, the pressure drop was decreasing through the first three sampling series. The catalyst bed was replenished following the August 1990 sampling series and prior to the May 1991 sampling series. The May 1991 series demonstrated that the TCE concentration in the effluent decreased after replenishing the catalyst bed. The frequency of replenishment of the catalyst will be dependent on the level of destruction desired and the permitted concentration of contaminants in the stack effluent.

The May 1991 data indicated that the formation of benzene and toluene was not from the oxidation of TCE. The concentration of benzene remained relatively constant in the stack effluent as the concentration of TCE in the feed stream was increased. The relationship between the concentration of toluene in the stack effluent and the concentration of TCE in the feed stream is not as clear since toluene was below the detection limits in the stack sample from the first TCE spike of the feed stream and field blank samples indicated the potential existed for toluene contamination. Mechanisms by which these and other PICs are formed cannot be specifically identified. Potential mechanisms for the formation of PICs were discussed in Section I.

SECTION IV

COST INFORMATION

A. WURTSMITH DATA

The evaluation of the catalytic oxidation unit also included collecting accurate cost data for operating the system. The collection and evaluation of this cost data are discussed below.

The capital cost of an ARI fluidized-bed oxidation unit with features similar to those of the oxidation unit in Building 5000 at Wurtsmith AFB is approximately \$83,000 for the equipment and \$15,000 for the installation*.

Wurtsmith AFB personnel routinely monitor the monthly electrical and natural gas usage by Building 5000. The electrical and natural gas usages and costs for Building 5000 were obtained from the Wurtsmith AFB Environmental Coordinators Office over the period of October 1988 through April 1991; however, these costs are for the whole building rather than for the catalytic oxidation unit itself. This building's sole purpose is to house the air stripping columns, the oxidation unit, and the associated equipment. The four main electrical power consumers in the building are (1) the air stripper blowers, (2) the air stripper water pumps, (3) the oxidation unit blower, and (4) the air compressor to operate the pneumatic controls. The power requirements for the air stripper blowers and water pumps probably overshadow the latter two consumers. There are two major consumers of natural gas in the building. The catalytic oxidation unit uses natural gas to preheat the feed stream to the catalyst bed temperature, and the building is heated with natural gas as needed. For the purposes of this report, the total cost of electrical and natural gas usages is used to determine the utility costs for the oxidation unit with the recognition that this will be a conservative value. The monthly usage and cost for the electricity and natural gas are shown in Tables 10, 11, and 12 for fiscal years 1989, 1990, and 1991, respectively.

*B. Sheffer, ARI, telephone conversation, 6 July 1990.

TABLE 10. FISCAL YEAR 1989 UTILITIES USAGE AND COST DATA

Month	Natural Gas		Electricity	
	Usage (m ³)	Cost (\$)	Usage (kWh)	Cost (\$)
October 1988	17,750	2,394	11,552	554
November	16,510	2,227	11,887	571
December	16,920	2,282	9,965	478
January 1989	12,550	1,693	11,155	535
February	7,671	1,035	4,538	218
March	7,371	994	4,200	202
April	787	106	1,252	60
May	11,675	1,575	3,672	176
June	17,330	2,338	11,562	555
July	1,010	136	4,820	231
August	18,200	2,455	7,913	380
September	9,110	1,230	8,191	393
TOTAL	136,900	18,465	90,707	4,353

TABLE 11. FISCAL YEAR 1990 UTILITIES USAGE AND COST DATA

Month	Natural Gas		Electricity	
	Usage (m ³)	Cost (\$)	Usage (kWh)	Cost (\$)
October 1989	11,670	1,574	8,516	337
November	18,950	2,556	10,669	507
December	20,060	2,267	11,321	544
January 1990	22,850	2,582	13,120	625
February	17,180	1,942	10,230	505
March	19,070	2,156	11,065	543
April	18,400	2,079	10,681	553
May	16,210	1,831	9,765	521
June	16,830	1,901	10,741	567
July	18,790	2,123	11,598	610
August	17,090	1,931	10,781	564
September	16,780	1,897	12,048	622
TOTAL	213,880	24,839	130,535	6,498

TABLE 12. FISCAL YEAR 1991 UTILITIES USAGE AND COST DATA

MONTH	NATURAL GAS		ELECTRICITY	
	USAGE (CUBIC METERS)	COST (\$)	USAGE (KWH)	COST (\$)
October 1990	16,320	1,845	9,666	496
November	14,770	1,669	12,473	532
December	10,170	1,221	12,225	560
January 1991	37,730	4,530	14,645	730
February	13,630	1,637	10,185	530
March	15,970	1,918	11,137	583
April	18,260	2,193	12,757	637
TOTAL*	217,470	25,737	83,088	6,974

*Total values represent projected annual amounts.

Data were obtained from Wurtsmith AFB personnel regarding the quantity of water treated by the air strippers at this location during the same period. Using these data and the utility cost data, the utility cost may be expressed with respect to the quantity of water treated. Table 13 shows the annual quantity of water treated by the strippers and the electrical and natural gas costs for fiscal years 1989 through 1991. The average utility cost per 1000 gallons of water treated is also shown in this table. Reduction of mechanical problems and fewer shutdowns are responsible for decreasing the average utility cost for operating the system.

B. COMPARISON TO OTHER SYSTEMS

Counce, Wilson, and Thomas have developed a Multiplan® spreadsheet for estimating the costs associated with an air stripping system combined with two types of emissions control systems (Reference 6). Their spreadsheet was used to generate cost data for comparison with (1) a catalytic incinerator, and (2) a carbon adsorption unit. The spreadsheet generates cost estimates in terms of 1990 dollars. For the purposes of this exercise, it was assumed that the air stripping system treated 568 liters/minute (150 gallons/minute) with 0.57 m³/second (1200 ft³/minute) air.

1. Catalytic Incinerator

The spreadsheet generated a capital cost estimate of \$46,000 for the catalytic incinerator and \$28,000 for the installation cost. Annual electrical costs were estimated to be approximately \$1200. The annual cost for fuel generated by the spreadsheet was \$61,000; however, this cost does not compare directly to the Wurtsmith incinerator fuel cost because this cost is for fuel oil as opposed to natural gas. Equation (6) shows the conversion of the cost of the fuel oil to the cost of the natural gas and assumes that the fuel oil preheater is 70 percent efficient.

$$(\$61,000) \cdot (0.70) \cdot \frac{(\$3.2/10^6 \text{ BTU Nat. Gas})}{(\$6.1/10^6 \text{ BTU Fuel Oil})} = \$22,400 \quad (6)$$

The total estimated annual utility cost generated from this comparison is \$23,600. Converting this cost to the basis shown in Table 13 yields an estimated average utility cost of \$0.30 per 1000 gallons of water treated. The cost difference between the Wurtsmith system and the estimated cost can be attributed to the estimates generated from the spreadsheet are for an idealized and optimum system. The Wurtsmith system is not an ideal system since it is occasionally shut down for maintenance either to the incinerator or the air-stripping system. There is also a small difference which can be attributed to inflation between 1990 and 1991.

TABLE 13. SUMMARY OF UTILITY COST DATA

	FY 1989	FY 1990	FY 1991*
Quantity of Water Treated by Air Strippers (1000 gallons) ^b	47,436	82,681	90,619
Electrical Costs (\$) ^c	4,354	6,498	6,974
Natural Gas Costs (\$) ^c	18,465	24,840	25,737
Average Utility Cost (\$ per 1000 Gallons of Water Treated)	0.481	0.379	0.361

*Data was obtained for this fiscal year through April 1991. Values are projected through September 1991.

^bData provided by Wurtsmith AFB Water Plant Personnel.

^cData provided by Wurtsmith AFB Civil Engineering Department.

2. Activated Carbon Bed

Most activated carbon bed systems have dual carbon adsorption beds so that one adsorption bed can be on line while the other adsorption bed is being regenerated. The size of the carbon adsorption beds are dependent on the desired time between regenerations of the carbon. The capital cost is consequently dependent on the size of the carbon adsorption beds. Comparing the capital cost of carbon adsorption equipment to the Wurtsmith system is dependent on the desired time between regenerations. For example, the spreadsheet predicts a capital cost of \$220,000 for a system with 60 days between regenerations, \$310,000 for 180 days between regenerations, and \$450,000 for 360 days between regenerations. In calculating annual expenses, the spreadsheet predicts the cost for operating the system and regenerating the carbon will be the same regardless of the regeneration schedule. The cost of electricity is estimated to be \$1200. The cost of fuel oil for preheating the air stream to control the humidity level is estimated to be \$2200 (\$1150 for natural gas equivalent), and the cost of regenerating the carbon beds is estimated to be \$9400. The regeneration costs include the cost of disposal of the contaminants desorbed from the carbon.

The total estimated annual utility cost for this system is \$11,750. Converting this cost to the cost per 1000 gallons of water treated generates an estimated average utility cost of \$0.15 per 1000

gallons of water treated. This estimated utility cost is one-half the estimated utility cost for the catalytic incinerator system discussed above; however, the capital cost of the two systems favors the catalytic incinerator. Using the capital cost of \$220,000 for an activated carbon system and \$74,000 for the catalytic incinerator, it would require approximately 12 years before the annual utility savings from using the activated carbon system offset the capital difference between the two systems.

SECTION V

CONCLUSIONS

The results have demonstrated that the TCE catalytic oxidation unit at Wurtsmith AFB destroys TCE with approximately 99 percent destruction efficiency when operated at the vendor recommended temperature of 370°C (700°F) and when the unit contains greater than or equal to 19 cm (7.5 inches) depth of catalyst as indicated by the pressure drop across the catalyst bed. The data indicate that the concentration of TCE in the stack gas increases with operating time. This is most reasonably attributable to the attrition of the fluidized bed of catalyst granules. The frequency of replenishing the catalyst bed with fresh catalyst should be determined by the level of destruction efficiency required and the permitted effluent contaminant concentration allowed.

Benzene and toluene were the PICs observed most often and in the highest concentrations. The results indicated that the formation of these compounds was not due to the oxidation of the TCE, but the results do not definitely identify the mechanism which forms these PICs. Benzene is most likely formed through a series of reactions initiated by the combustion of natural gas.

The VOST results did not indicate the formation of chlorinated hydrocarbons, and the samples collected and analyzed by the RTI revealed only a negligible quantity of HCl and Cl₂ in the stack effluent. The fate of the chlorine atoms from the destruction of the TCE molecules remains unknown.

SECTION VI

RECOMMENDATIONS

The report identified several significant discrepancies in the various analytical data reported by the contract laboratory. It has proven very difficult to resolve these discrepancies after the fact. These problems highlight the importance of having on-site analytical capabilities, so that at least some measure of data quality can be achieved quickly. Additional sampling and analyses can be done when problems are identified. This approach would not eliminate the need for contract laboratory analyses for verification and QA purposes, but would rather add substantially to the overall data quality.

The major contaminant of concern in this study was TCE, and the destruction efficiency results are reported in terms of destruction of TCE. Therefore, these results are not necessarily applicable to oxidation units used for the destruction of other volatile compounds (e.g., benzene). Therefore, it is recommended that similar units that treat volatile organic compounds other than TCE should also be sampled for comparison to the results of this project.

SECTION VII

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APPENDIX A

REPORT ON RESULTS OF CHLORINE AND HCl SAMPLING FROM THE CATALYTIC INCINERATOR AT WURTSMITH AFB ON OCTOBER 12 AND 13, 1989

RTI PROJECT NO. 473U-4482

SAMPLING PROCEDURE

Each impinger train consisted of three impingers in series, the first two containing 15 mL 0.1N H_2SO_4 and the third containing 15 mL 0.1N NaOH. Three trains were run in parallel at each location (blower outlet, bed inlet and stack), two for replicates and one spiked train (0.1N H_2SO_4 spiked with 3.62 $\mu g/mL$) to determine recovery efficiency. Figure 1 shows the sampling locations. The incinerator temperature (catalyst bed) was 900°F. Sampling probes were inserted into the gas stream at each location and continuous samples were pulled through the trains using calibrated personal sampling pumps. The flowrate through each train was about 1 liter/min and sampling time was two hours. All lines were wrapped in heating tape and heated above 100°C to prevent condensation of water vapor. The contents of each impinger were then analyzed using ion chromatography. The results are summarized in Table 1.

ANALYTICAL PROCEDURES

The field samples collected in midget impingers were analyzed without any dilution for chloride ion by ion chromatography (IC). Non-suppressed IC was performed with a Perkin-Elmer Series 10 Pump, a Rheodyne Series 7010 sample injection valve, a 100x4.1mm Hamilton PRP-X100 Anion Column, and a Milton Roy detector with a temperature-controlled conducting cell. The eluent was 4mmol potassium hydrogen phthalate and the eluent flowrate was 2 mL/minute. A Spectra Physics electronic integrator was used to produce chromatograms and provide integration of the chloride peak area. A Lotus spreadsheet was used to calculate the slope and y-intercept for the linear regression equation of the standards, calculate percent deviation of the standards from the calibration line, calculate the sample results as total HCl, and using the gas sample volume, calculate the flue gas HCl concentrations.

The IC system was calibrated each day prior to analysis with a series of four calibration standards, bracketing the field sample concentrations, prepared in the impinger reagent and diluted to a representative concentration of reagent. The instrument calibration was repeated at the conclusion of each day's analysis.

DISCUSSION OF RESULTS

Blower Outlet

No HCl or Cl_2 was detected. The measured Cl^- ion values were close to the blank values. The spiked sample analysis showed good recovery of chloride ion ($3.62 \pm 1.11 = 4.73 \mu g/mL$; measured 4.64 $\mu g/mL$).

Catalyst Bed Inlet

Train #1 showed 30.8 $\mu\text{g/mL}$ Cl^- and Train #2 showed 31.7 $\mu\text{g/mL}$ in the first H_2SO_4 impinger and no measurable Cl^- ion in the second H_2SO_4 impinger, indicating no breakthrough of HCl from the first impinger over the two hour sampling period. No measurable Cl^- ion was detected in the NaOH impinger, suggesting no Cl_2 present.

The HCl concentration corresponding to the measured Cl^- ion concentration is 2.4 ppm, corrected for the blank value of 0.8 $\mu\text{g/mL}$ for H_2SO_4 . This is calculated as follows:

$$\text{Mean } \text{Cl}^- \text{ concentration} = (30.8 + 31.7)/2 = 31.25 \mu\text{g/mL}.$$

$$\text{Corrected value of } \text{Cl}^- \text{ concentration} = 31.25 - 0.8 = 30.45 \mu\text{g/mL}.$$

$$\text{Total sample volume} = 15 \text{ mL}.$$

$$\text{Hence, total } \text{Cl}^- \text{ present} = 30.45 \times 15 = 456.75 \mu\text{g}.$$

$$\begin{aligned} \text{Moles } \text{Cl}^- \text{ present} &= \text{moles } \text{HCl} \text{ present} = (456.75 \times 10^{-6})/35.5 \\ &= 1.29 \times 10^{-5} \text{ moles.} \end{aligned}$$

$$1 \text{ mole } \text{HCl} = 22400 \text{ cm}^3 \text{ HCl}.$$

$$\text{Hence, HCl present} = 1.29 \times 10^{-5} \times 22400 = 0.2882 \text{ cm}^3.$$

$$\begin{aligned} \text{Total flow through impinger over sampling period} &= 1000 \text{ cm}^3/\text{min} \times 120\text{min} \\ &= 1.2 \times 10^5 \text{ cm}^3. \end{aligned}$$

$$\begin{aligned} \text{Hence, gas-phase HCl concentration} &= 0.2882/(1.2 \times 10^5) = 2.4 \times 10^{-6} \\ &= 2.4 \text{ ppm.} \end{aligned}$$

Stack

There was no measurable HCl or Cl_2 . This is consistent with work in our lab with the same catalyst, which indicates either reaction of these species with the catalyst or formation of oxides of chlorine at 900°F .

Summary

It appears that maximum HCl formation occurs in the preheater. The low values of HCl and Cl_2 at the stack may be due to reaction with the catalyst or oxidation of these species.

Table A-1. Results of IC Analyses From Wurtsmith AFB Air Stripper Incinerator Study

<u>Position #1: Feed</u>			
<u>Train No.</u>	<u>H₂SO₄ Impinger #1 Total $\mu\text{g/mL Cl}^-$</u>	<u>H₂SO₄ Impinger #2 Total $\mu\text{g/mL Cl}^-$</u>	<u>NaOH $\mu\text{g/mL Cl}^-$</u>
1	1.11	ND	0.3
2	0.6	ND	ND
3 (Spike)	4.64	ND	ND
<u>Position #2: Inlet</u>			
1	30.8	ND	ND
2	31.7	0.9	0.9
3 (Spike)	0.6*	ND	ND
<u>Position #3: Stack</u>			
1	1.1	ND	ND
2	4.3	ND	ND
3 (Spike)	20.8	ND	ND
	Blank H ₂ SO ₄	0.8 $\mu\text{g/mL Cl}^-$	
	Blank NaOH	0.3 $\mu\text{g/mL Cl}^-$	
	ND	Not Detected	

* The pH of this sample was ~ 9, may have used NaOH by mistake.

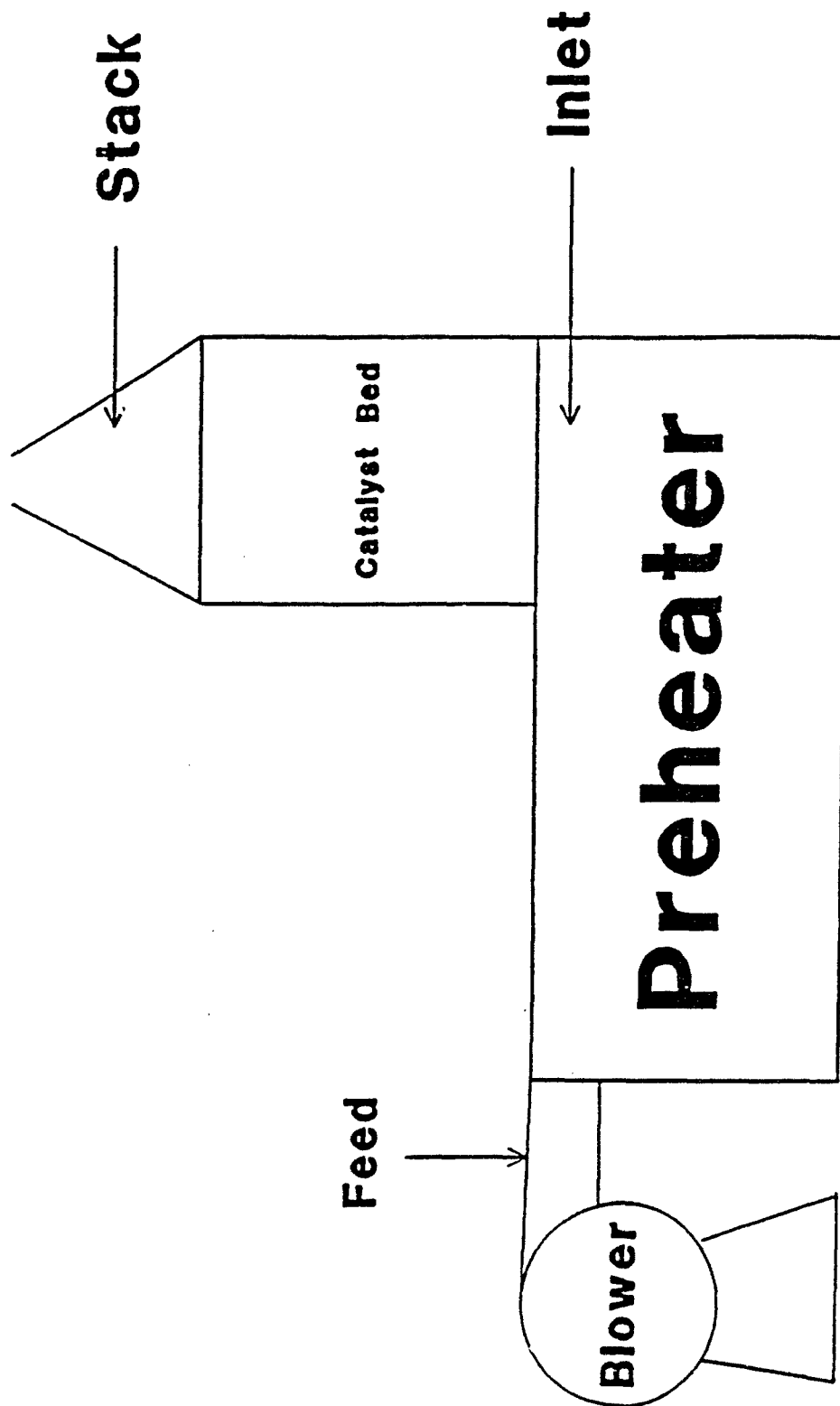


Figure A-1. Sampling Locations